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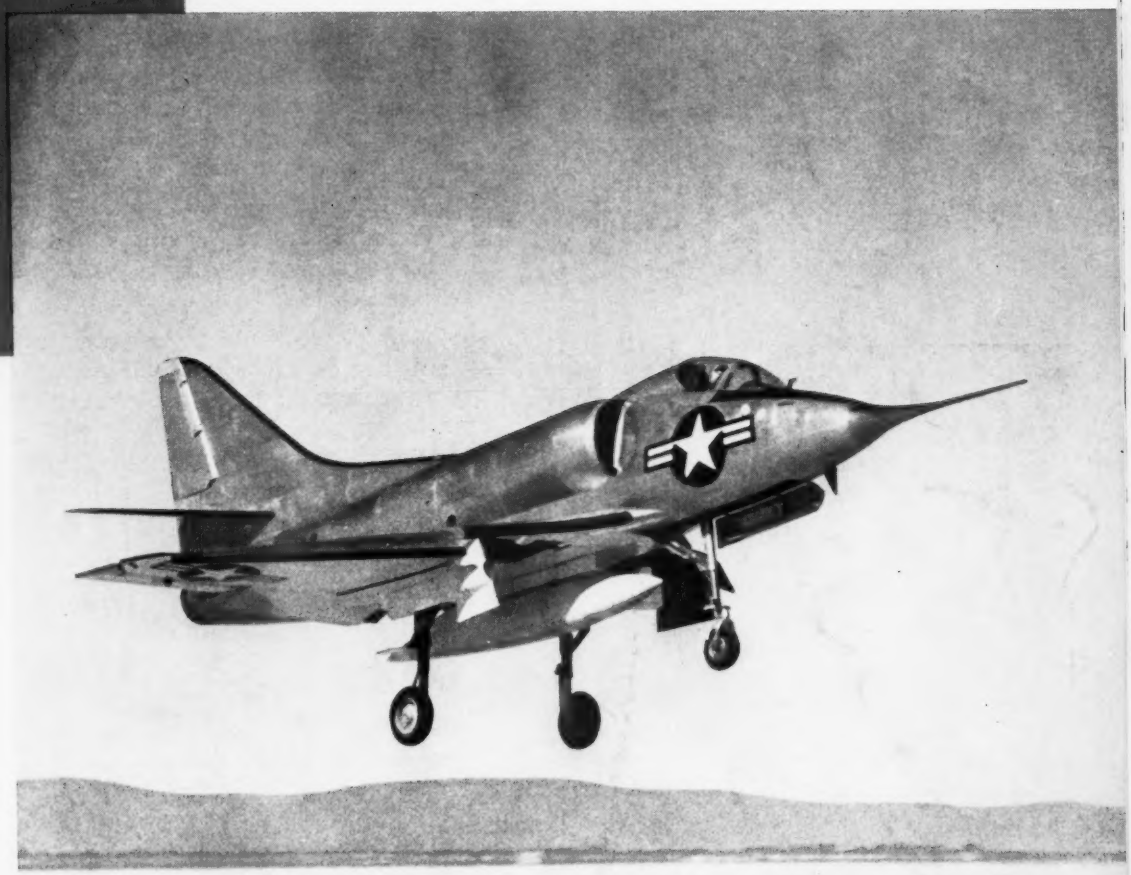
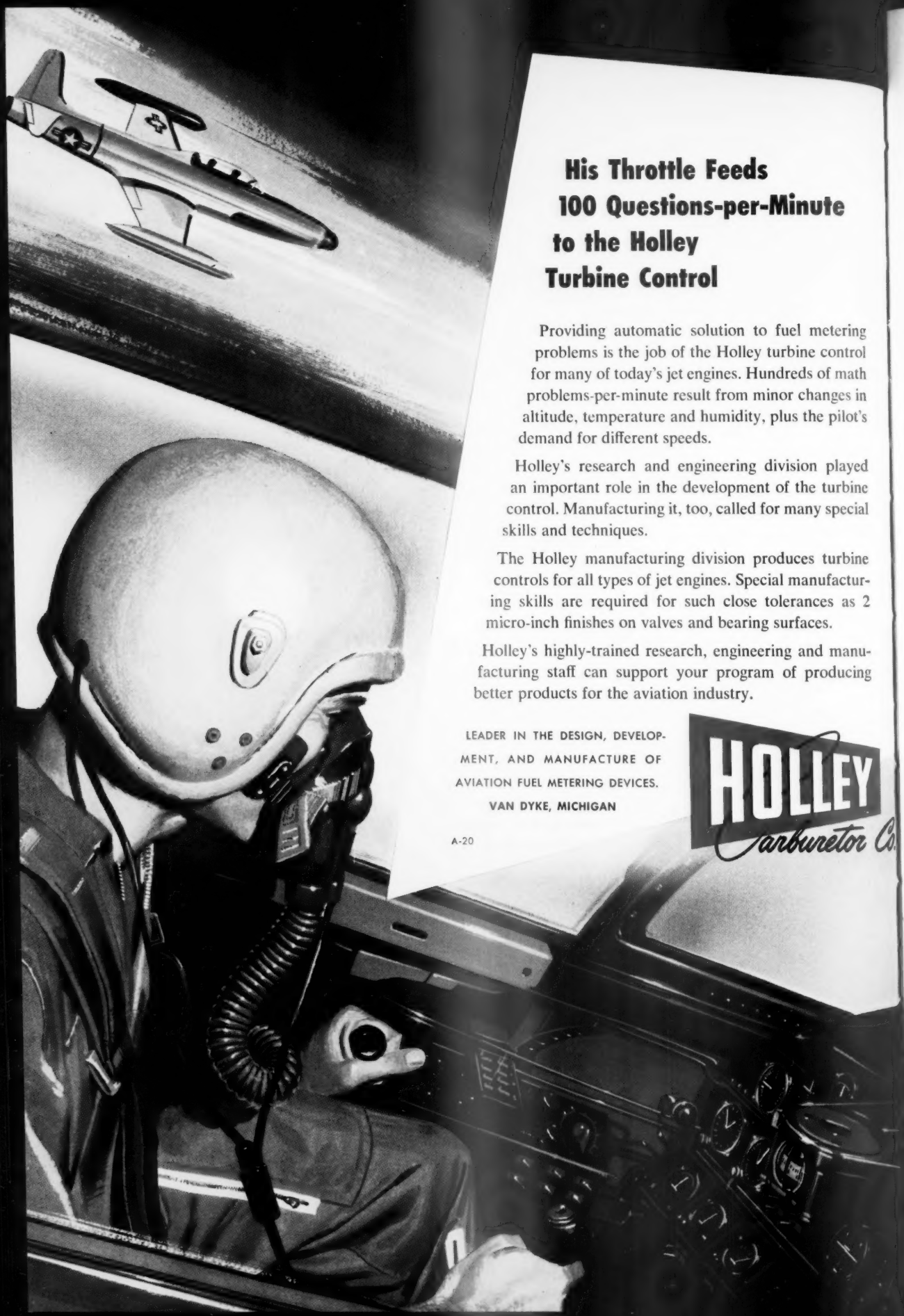
Aeronautical Engineering REVIEW



SEPTEMBER, 1954



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Aeronautical Engineering Review

Vol. 13—No. 9 September, 1954

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Cover—The Douglas A4D Skyhawk, which made its first flight at Edwards AFB, Calif., on June 22, is America's smallest and lightest jet combat plane. Now in production for the U.S. Navy at Douglas Aircraft Company, Inc., this bantam bomber is designed to operate from all sizes of Navy carriers and from short landing fields. It is less than half the size of many current operational jet fighters, has a combat radius greater than many present propeller-driven fighters, and can carry atom bombs or rockets, machine guns, missiles, and other weapons. The A4D Skyhawk is powered by a J-65 Sapphire turbojet engine, manufactured by Curtiss-Wright Corporation.

Published Monthly by the

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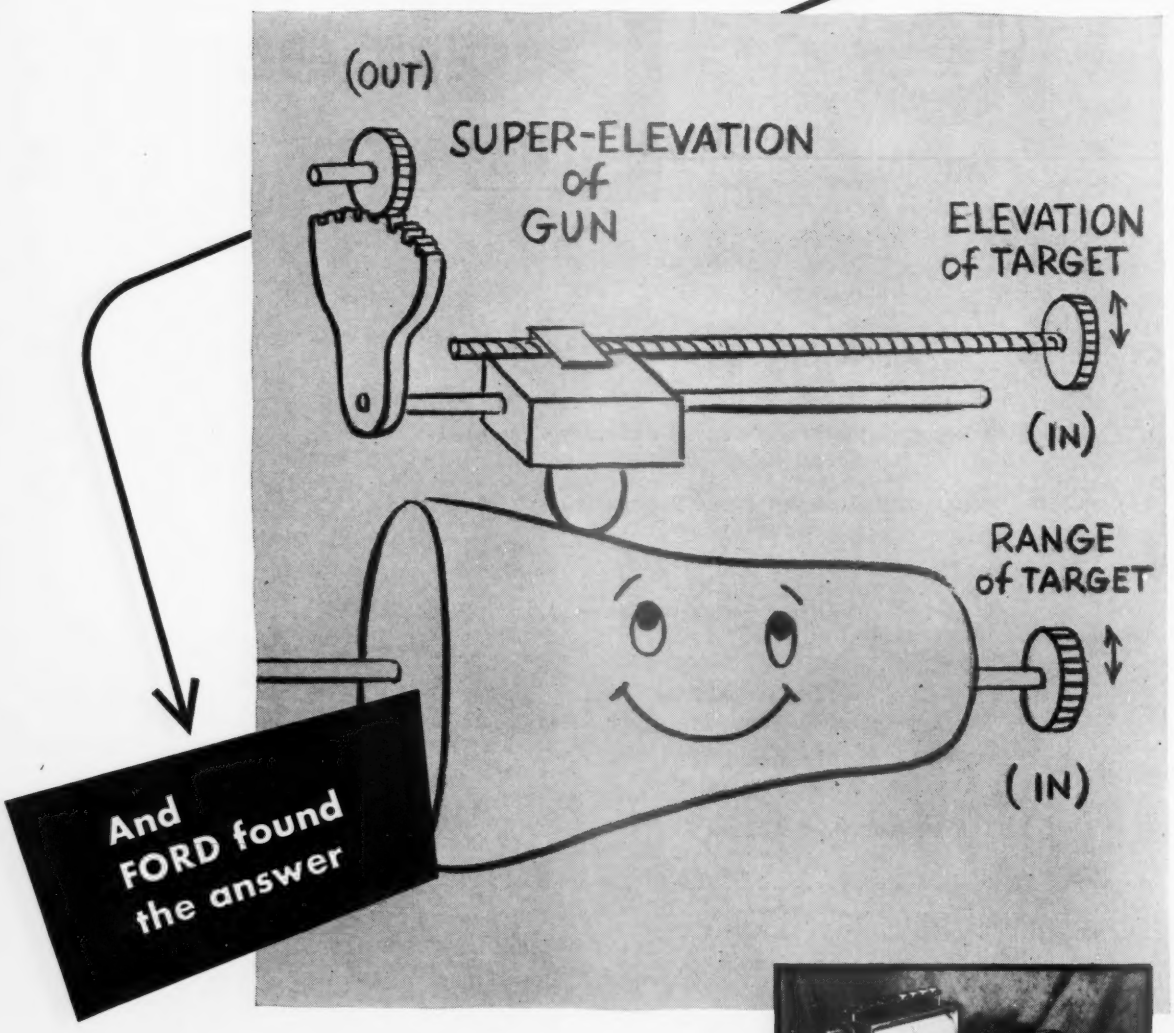
HOW TO TAP THE BRAIN
of a piece of metal



In making computers, such information as mathematical functions can be stored in a precision-cut cam, thus allowing its follower to be displaced in accurate reply to the input position of the cam. Ford Instrument Company designs and makes cams of all sizes and shapes to achieve these results. To manufacture such cams with the precision demanded, the engineers of Ford Instrument have devised remarkable automatic machines which, by following a carefully plotted ink line on a roll of paper, cut the exact shape into the metal. Then, careful point-by-point checks, sometimes as many as 2000 measurements, insure finest accuracy.

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I.A.S. News Notes

September 1954

CAI-IAS JOINT MEETING

The first joint meeting of the newly formed Canadian Aeronautical Institute, and the Institute of the Aeronautical Sciences will be held at the Sheraton-Mount Royal Hotel, Montreal, Canada, October 14-15, 1954. A total of nine papers--five Canadian and four American--will be presented at the three technical sessions. These sessions are scheduled for Thursday morning and afternoon and Friday morning.

On Friday afternoon, an inspection tour of the Canadair Ltd., plant has been planned. This tour may involve special arrangements for persons who are neither Canadian nor U.S. citizens. Those in this category who are planning to attend this international meeting should so advise in a letter addressed to: A.E. Ainger, Public Relations Dept., Canadair Ltd., P. O. Box 6087, Montreal, Canada. This letter should include information on the writer's country of citizenship, his title or position, company or organization.

The CAI Montreal Branch has arranged for a block of rooms to be set aside at the Sheraton-Mount Royal Hotel. Those wishing to reserve rooms should write to the Hotel not later than October 5, making reference to the fact that they are attending the CAI-IAS meeting.

* * * * * * * *

TURBINE-POWERED AIR TRANSPORTATION MEETING PROCEEDINGS

Proceedings of the National Turbine-Powered Air Transportation Meeting, held in Seattle, Wash., on August 9-11, 1954, are being published by the Institute and will be available about November 1. This bound volume will contain all papers presented at the 3-day meeting.

The Proceedings may be obtained by writing to the Publications Department, Institute of the Aeronautical Sciences, 2 E. 64th Street, New York 21, N. Y. The price per copy is $3.50 to IAS members and $6.00 to nonmembers.

* * * * * * * *

1953 TELEMETERING CONFERENCE RECORD AVAILABLE

Those persons who have been trying to secure copies of the 1953 National Telemetering Conference Record will be interested to learn that the IAS has obtained a limited number of this 230-page publication. It is available through the IAS Publications Department at $2.00 per copy.

This edition contains the complete transcripts of the talks and papers presented at the 1953 Conference held in Chicago, May 20-22, 1953. This Conference was jointly sponsored by the AIEE, IRE, ISA, and IAS.

* * * * * * * *

NEW STUDENT MEMBER PUBLICATION

The first program to be instituted for the benefit of aeronautical students, under the Minta Martin Aeronautical Student Fund, has been completed. A new student publication, "The 1954 Award Winning Papers--IAS Student Paper Competitions," will be ready for distribution in early October. Plans are under way to standardize competition prizes and establish uniform requirements for all participants in the spring competitions.

* * * * * * * *

NEW IAS CORPORATE MEMBER

American Non-Gran Bronze Company, Berwyn, Pennsylvania

* * * * * * * *

NATIONAL MEETINGS CALENDAR

Oct. 14-15--Joint meeting of the Canadian Aeronautical Institute and the IAS, Sheraton-Mount Royal Hotel, Montreal, Canada

Dec. 17--Eighteenth Wright Brothers Lecture, U. S. Chamber of Commerce Bldg. Auditorium, Wash., D. C. Dr. Bo Lundberg, Director, Aero. Research Inst. of Sweden, Lecturer.

Jan. 24-28--Twenty-third Annual Meeting and Honors Night Dinner, Hotel Astor, New York, New York

June 21-24--Fifth International Aeronautical Conference, IAS Building, 7660 Beverly Blvd., Los Angeles, California

* * * * * * * *

CALENDAR OF SECTION MEETINGS

Sept. 16--Los Angeles Section: IAS Building. Social Hour, 6:00 p.m.; Dinner, 7:00 p.m.; Meeting, 8:15 p.m. "New Techniques in Carrier Operation" by Lt. Cmdr. James L. Holbrook, USN, Ships Installation Division, BuAer, U. S. Navy.

Sept. 28--San Diego Section: IAS Building. Social Hour, 6:30 p.m.; Dinner, 7:00 p.m. General subject--the Ryan "Firebee" target drone. Annual business meeting and installation of officers to be held.

Oct. 12--Indianapolis Section: Meeting location unknown at press time. Speaker - Abe Silverstein, Associate Director, Lewis Flight Propulsion Laboratory, NACA.

Oct. 14--Los Angeles Section: IAS Building. Specialist Meeting, 7:30 p.m. "Flight Operations of the Mountain Wave Project" by Dr. Wolfgang B. Klemperer, Research Engineer, Douglas Aircraft Co., Inc.

* * * * * * * *

IAS News

A Record of People and Events of Interest to Institute Members

Summer Meeting Report

Los Angeles, Calif., June 21–24, 1954

THE INCREASING IMPORTANCE of the Institute's national summer meetings on the West Coast was reflected by both the quantity and quality of people attending and participating in this year's sessions. The caliber of papers presented, as well as the smooth-running operation of the dinner, field trip, and security-closed sessions, elicited many favorable comments from the 900-and-more registrants who were present.

Since arrangements for these summer meetings are handled largely by members of the Los Angeles Section, all credit for a highly successful undertaking goes to this year's Section Officers and the Chairman and members of the Program Committee.

▸ **Technical Sessions**—Summaries of the nine open sessions have been prepared by the various chairmen and will be published in the October issue of the REVIEW. Most of the individual papers (some of which appear in this issue) will be published as soon as possible in either the REVIEW or the JOURNAL. A limited number of preprints of certain papers are still available. (See page 145, August REVIEW).

▸ **Dinner**—This year's dinner was the largest to be held by the Institute on the West Coast. More than 900 persons crowded into the Statler Hotel Ballroom to honor Donald Douglas, the Award winners, and the thirtieth anniversary of the first global flight.

An unusual wall decoration, beautifully executed through the joint efforts of Northrop, North American, and Douglas aircraft companies, effectively emphasized the theme of the dinner and Mr. Douglas' speech. Excerpts from the latter, "Our Shrinking Globe," appeared as a guest editorial in the August REVIEW.

Presentation of the Bane and Chanute Awards by Toastmaster Lee Atwood, IAS President; the interesting reminiscing by H. H. Ogden, First Lieutenant, USAF (Ret.), one of the crew members of the first round-the-world flight: remarks by Glenn L. Martin and the Institute's Founder, Lester D. Gardner; and presentation by Donald Douglas of the "World Cruiser" model to R. C. Heppe for the Institute's Durand Aeronautical

R. R. Heppe
1954 Chairman, Los Angeles Section

IAS Group at Edwards Air Force Base on June 24.

Museum were other highlights of the evening's program.

▶ **Field Trip**—Approximately 250 security-cleared members of the Institute braved the desert heat (and a 5:30 a.m. breakfast at the IAS building) to visit Edwards AFB on the morning following the dinner. An inspection of the facilities, luncheon at the Officers' Club, and several equipment demonstrations were included in the day's program. Unfortunately, Brig. Gen. J. Stanley Holtner, Commander of the Test Center and host for this occasion, was called away on official business. However, the officers and members of his staff did a creditable job of making the group welcome.

(*Above*) Annual Summer Meeting Dinner in the Ballroom of the Hotel Statler, June 23.

(*Left, opposite page*) IAS members watch demonstration of Bell X-1A being loaded into the B-29 mother ship at Edwards AFB.

(*Right*) Effective display, provided by North American Aviation, Inc., for the foyer of the IAS building, depicts the theme of the summer meeting.

West Coast IAS Student Branch Conference and Industry-Faculty Conference

The Fourth Annual West Coast Conference of IAS Student Branches was held by the Los Angeles Section on May 6, 7, and 8 at the Los Angeles building of the Institute of the Aeronautical Sciences. The Los Angeles Section presented concurrently with the Student Conference the First Annual West Coast Industry-Faculty Conference, on May 6 and 7.

Approximately 140 IAS student members registered for the student conference, while 18 faculty members and 21 industry representatives participated in the Industry-Faculty Conference. Ten of the eleven schools invited to take part in the student conference sent representatives; eight of the schools had papers read at the meeting.

The meeting got under way at 9:00 a.m. on Thursday, May 6, with welcoming addresses by R. Richard Heppe, Chairman of the Los Angeles Section, and Winfield H. Arata, Jr., Chairman of the Student Activities Committee of the Los Angeles Section. The undergraduate papers were presented during the Thursday morning and afternoon sessions, while the graduate papers were delivered on Friday morning. These papers and their authors are:

Thursday morning session: "The Design, Construction, Testing, and Launching of the Northrop Research Vehicle" by Daniel L. DiIullo, Northrop Aeronautical Institute; "The Design, Construction, and Testing of a Solid-Propellant Rocket Motor" by Lowell R. Shirley and Lloyd G. Birrer, Jr., California State Polytechnic College; "Combustion Instability in Liquid-Propellant Rockets" by Ronald F. Dettling, California Institute of Technology; and "Vapor Pressure Measurements of Jet Fuels over an Extreme Temperature Range" by James V. Dutzi, University of California.

The winners in the undergraduate division of the Los Angeles Section's Fourth Annual West Coast Conference of IAS Student Branches are shown. From *left to right* are: Gordon Woodcock, first-place winner; James V. Dutzi, second-place winner; and Lowell R. Shirley and Lloyd G. Birrer, Jr., third-place winners.

Thursday afternoon session: "Design and Construction of a Radio-Controlled Airplane" by Gordon Woodcock, Oregon State College; "Mass Production Features for a Personal-Type Aircraft" by Harold E. Emigh, Northrop Aeronautical Institute; "The Use of a High-Speed Water Jet for Determining the Hydrodynamic Characteristics of Planing Surfaces" by Richard A. Balser, University of Washington; and "The Design and Construction of a Vertical Take-Off Model Airplane" by Leroy Presley, Oregon State College.

Friday morning session (Chairman, Paul Strohm, Trans World Airlines, Inc.): "A Low-Lag Altimeter" by Philip Wingrove, University of Washington; "Base Pressure and Static Pressure for a Cone-Cylinder in Hypersonic Flow" by William D. Harkins, California Institute of Technology; "An Aeropulse Thermojet Utilizing a Positive Displacement Compressor" by Capt. Roy J. Edwards, USMC, U.S. Naval Postgraduate School; "The Hypersonic Shock Tube" by Yusuf A. Yoler, California Institute of Technology; "The Pitching Moment Coefficient of a New Family of Wing Sections" by Lt. L. C. Baldwin, USN, U.S. Naval Postgraduate School; and "The Effect on Induced Drag of a Number of Aircraft in Close Proximity" by O. E. Sipe, Jr., University of California, Los Angeles.

Here are the winners of the graduate division in the Los Angeles Section's Fourth Annual West Coast Conference of IAS Student Branches. From *left to right* are: Philip Wingrove, third-place winner; William D. Harkins, first-place winner; and Yusuf A. Yoler, second-place winner.

Northrop Aircraft, Inc., and Hughes Aircraft Company were the hosts at the Thursday and Friday luncheons, respectively. On Friday afternoon and on Saturday morning and afternoon, tours of the following facilities were made: Lockheed Aircraft Corporation, Burbank; Douglas Aircraft Company, Inc., El Segundo; Pacific Airmotive Corporation, Burbank; Western Air Lines; and the U.C.L.A. and CalTech engineering laboratories.

The banquet, at which the Student Awards were made, was held Friday evening in the IAS Auditorium. J. L. Atwood, IAS President, gave a short talk on the importance of aeronautical engineers and aeronautical research to this country and its way of life. This was followed by the presentation of the Student Awards by the Judges Harold Luskin, Brooks Morris, and Eugene Frost.

Mr. Morris presented third-place prizes to Lowell R. Shirley and Lloyd G. Birrer, Jr., for their undergraduate paper and to Philip Wingrove for his graduate paper. The third-place prizes consisted of F-89 models, IAS Certificates of Merit, and checks of $25 each.

Mr. Frost presented the second-place awards to undergraduate James V. Dutzi and graduate Yusuf A. Yoler. These awards were Skyrocket models, IAS Certificates of Merit, and $50 checks.

The first-place winners were Gordon Woodcock, undergraduate division, and William D. Harkins, graduate division. Messrs. Woodcock and Harkins were given their awards by Mr. Luskin, who presented each with an F-86 model, IAS Certificate of Merit, and a check in the amount of $75.

After the presentation of the Student Awards, the banquet speaker, Harry K. Coffey, was presented. Mr. Coffey, Chairman of the Board, National Aeronautic Association, discussed "The Future Trends in Aviation."

Jerome C. Hunsaker Professorship

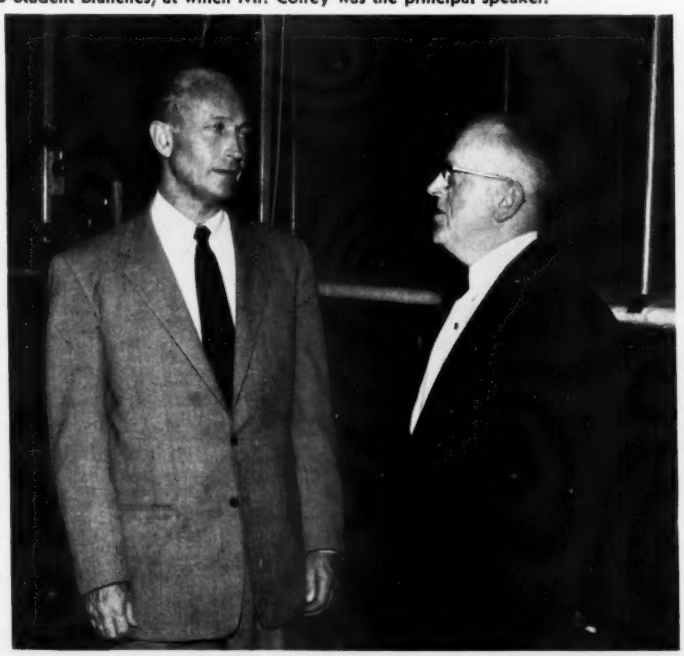
The Massachusetts Institute of Technology has announced that gifts totalling $275,000 have been received to establish a professorship in aeronautical engineering honoring Dr. Jerome C. Hunsaker, IAS Honorary Fellow, Founder and former Head of M.I.T.'s Department of Aeronautical Engineering, and now Professor (Emeritus) of Aeronautical Engineering at M.I.T. The present $275,000 endowment for the Jerome C. Hunsaker Professorship came from many donors throughout the aircraft industry. It is expected to be increased to $500,000 by subsequent gifts.

Seven M.I.T. alumni were named as having been instrumental in establishing this new fund. They are Major Gen. James H. Doolittle, IAS Honorary Fellow, Vice-President and Director, Shell Oil Company; Donald W. Douglas, IAS Honorary Fellow and Benefactor, President, Douglas Aircraft Company, Inc.; Rear Adm. Luis de Florez, FIAS, Chairman of the Board, The de Florez Company, Inc.; Major Lester D. Gardner, Founder of the Institute of the Aeronautical Sciences, former Chairman of the IAS Council, and IAS Fellow and Benefactor; Leroy R. Grumman, IAS Honorary Fellow, Chairman of the Board, Grumman Aircraft Engineering Corporation; Vice Adm. Edwin H. Land, Chairman of the Board, Polaroid Corporation; and Edward P. Warner, IAS Honorary Fellow, President of the Council, International Civil Aviation Organization.

Glenn L. Martin, IAS Honorary Fellow and Benefactor, Founder of The Glenn L. Martin Company, has donated $50,000 to the professorial fund to provide for the Minta Martin Aeronautical Lectures as a part of the Hunsaker Professorship.

Dr. Hunsaker, General Doolittle, Mr. Douglas, Admiral de Florez, Major Gardner, Mr. Warner, and Mr. Martin are all IAS Founder Members.

J. L. Atwood, IAS President and President of North American Aviation, Inc., is shown with Harry K. Coffey *(right)*, Chairman of the Board, National Aeronautic Association. This photograph was taken during the May 7 banquet of the Fourth Annual West Coast Conference of IAS Student Branches, at which Mr. Coffey was the principal speaker.



1953 Aviation Safety Award Winners

Pan American World Airways, Inc., Trans World Airlines, Inc., and United Air Lines, Inc., were among the 39 U.S. air lines that were named winners of the National Safety Council's Aviation Safety Award for going through 1953 without a passenger or crew fatality in air accidents. The annual award is given only to domestic, territorial, and overseas air carriers that fly scheduled passenger runs.

Pan American is credited with one year of safe operation and with having flown 2,889,332,000 passenger-miles without fatality to the end of 1953 and TWA with 3 years of safe operation and having flown 8,005,182,000 passenger-miles without fatality to the end of 1953. United is listed as having had 2 years of safe operation and 6,002,630,000 passenger-miles without fatality to the end of 1953.

All Council awards were made on the basis of official records of the CAB, and the total miles are those accumulated in scheduled passenger-carrying operations only.

Guggenheim Fellowships at Princeton

The names of eight men who have been selected to receive Daniel and Florence Guggenheim Jet Propulsion Fellowships for advanced study and research at the Guggenheim Jet Propulsion Center, Princeton University, were announced on July 8 by Harry F. Guggenheim, IAS Member, Honorary Member, and Benefactor, President of The Daniel and Florence Guggenheim Foundation, and Dr. Har-

(Continued on page 89)

Roy W. Elliott

Supervisor, IAS Technical Film Cataloging Project

Editorial

An Added Service

The Institute has been selected by the Air Research and Development Command to perform another important and useful service for the Air Force. This undertaking, formally known as the Technical Film Cataloging Project, went into effect on July 1 with full approval of the Council and is now in operation at the Institute's San Diego building.

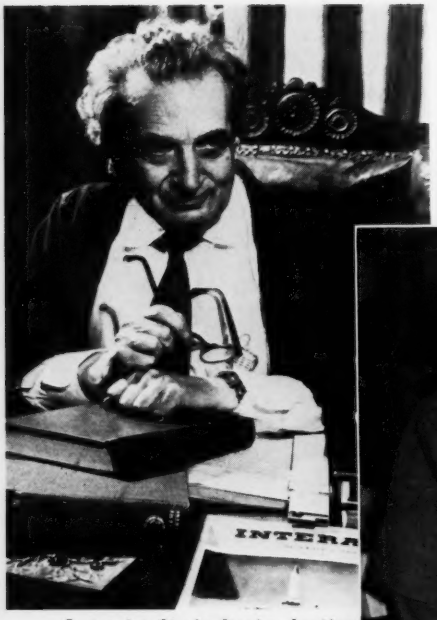
As the name implies, the purpose of the project is to locate, catalog, and establish the availability of all technical motion-picture films that might be of interest to the Air Force. The value of a comprehensive index of such material is obvious. Through it, both the Air Force and the industry will be able to locate pertinent films quickly and easily. Ultimately, much time and money will be saved merely by eliminating duplication in filming already available subject matter.

It is not intended that any films be stored or actually handled by the Institute. Complete catalogs and indexes will be maintained in both the West Coast and New York buildings. Requests for information relative to classified films in the Catalog will be cleared through Air Force channels. The proprietary rights of all reporting companies and agencies will be fully protected, since all requests for specific films will be made directly to the organization owning the film.

Responsibility for the supervision of this project has been placed in the hands of Roy W. Elliott. Mr. Elliott has been active in aeronautical circles for many years, was Director of Purchases for Cessna Aircraft Company before coming to San Diego, and was Sales Representative for The Langley Corporation previous to that engagement. While Comptroller of the University of Wichita, he was instrumental in setting up the university's Aeronautical Engineering School and served as Professor of Engineering in that institution. During World War II, he was a consultant to the CAA on Pilot Training in colleges. As a charter member of the Kansas Commission on Aviation Education, he did much to bring pertinent information to the schools of Kansas. A Tau Beta Pi and Sigma Xi from the University of Michigan, Mr. Elliott is well qualified for the research that has to be done in this instance.

This is a type contract that the Institute can handle well. It ties in perfectly with the normal function and operations of the organization and makes it possible for us to render another valuable service to the Armed Services and our members.

W.A.S.



Courtesy Ben Olender, Pasadena Star-News

Dr. Th. von Kármán, re-elected as AGARD Chairman for the current year.

Prince Bernhard of the Netherlands opens the Fourth General Assembly with an address of welcome on behalf of the Netherlands Government.

A Report on the

Fourth General Assembly of AGARD

DURING THE WEEK of May 3, 1954, leading aeronautical scientists of NATO assembled at the Kurhaus in Scheveningen, the Netherlands, for the Fourth General Assembly of the Advisory Group for Aeronautical Research and Development to the North Atlantic Treaty Organization.

Dr. Theodore von Kármán formally convened the Fourth General Assembly on May 5, 1954, in his capacity as AGARD chairman. Among the distinguished speakers representing several countries on this occasion was Prince Bernhard of the Netherlands who welcomed the gathering at the opening of the General Assembly.

The Fourth General Assembly marked the end of the two-year trial period for which AGARD was initially established by the NATO Standing Group. For this period the United States Air Force was designated as executive agent by the Standing Group and thus has provided the principal logistic support. The participating nations have concluded that the accomplishments of AGARD justify its continuation, and the Standing Group has endorsed this view. Therefore, this meeting also marks the advent of AGARD as an internationally funded activity of NATO. (See also Editorial, July.)

AGARD accomplishes its objective of furthering the advancement of the aeronautical sciences throughout NATO by holding periodic meetings at which technical information is disseminated and projects inaugurated which have as their aim the compilation of available data on scientific problems of particular importance to the defense of the NATO community.

There are four technical panels of AGARD—Wind Tunnel and Model Testing, Flight Test Techniques, Aeromedical, and Combustion Research. In addition there is a committee on Documentation.

The general scope of the presentations is indicated in the facing Index of authors and their papers. Typical of the quality of paper given is that of Handley-Page's Dr. Lachmann (see page 37 of the August issue of the REVIEW).

One of the most interesting features of the meeting was the round table discussion at the Wednesday afternoon General Assembly on the general subject of transonic flight by an international group of pilots who have done most of the world's transonic and supersonic flying. Excerpts from their presentations follow on page 44 of this issue.

Index of Papers Presented at Fourth General Assembly of AGARD

Key: B, Belgium; C, Canada; D, Denmark; F, France; I, Italy; NE, Netherlands; T, Turkey; UK, United Kingdom; US, United States. An asterisk denotes those papers presented in general assemblies; the others were given in the several panels.

Aldwinckle, R. M. (C) Operation of Aircraft at Low Temperatures (delivered by Green)*

Balchen, Bernt (US) Cold Weather Problems*

Brun, Edmond A. (F) Review of Aircraft Icing Problems

Carpentier, Roger (F) Subjective Experiences and Reactions During Flight Testing in the Transonic Region*

Cleverdon, C. W. (UK) Availability of Reports

Connelly, E. D. (US) Documentation Problems of AGARD

Conover, R. E. (US) Prepared Comments on Oscillographic Recording Techniques

Crossfield, A. S. (US) Subjective Experiences and Reactions During Flight Testing in the Transonic Region*

Désirant (B) Airborne Electronic Equipment*

Dossing, J. (D) Anthropometrical Research in the Royal Danish Air Force

Driscoll, Col. J. J. (US) Flight Testing for Operational Requirements

Ducros, E. (F) Statistiques de Biométrie Médicale Elémentaire Relatives au Personnel Navigant de l'Armée de l'Air Française

Duke, Neville (UK) Subjective Experiences and Reactions During Flight Testing in the Transonic Region*

Duwez, Pol (US) Some Aspects of Aeronautical Materials Research*

Evrard, E. (B) Discussion on Anthropometry

Fouré (F) Applied Problems in Carbon Formation

Frazer, Stubbs Large Scale Collection of Icing Data

Frenot, M. G. (F) Interlingual Dictionary

Graves (US) Diffusion Flames in Heterogeneous Combustion

Gough, M. N. (US) Prepared Comments on Measurement of Servo-Control Characteristics

Graybiel, Ashton (US) Studies on the Life History of the Naval Aviator

Greatrex (UK) Design of Jet Engine Driven Wind Tunnels

Gregson, E. J. (UK) Measurement of Noise and Vibration in Flight

Grether, W. F. (US) Aircraft Instrument Dials, Instrument Layout and Cockpit Design

Hesse, W. J. (US) A Simple Gross Thrust Meter and Some of its Applications at the Naval Air Test Center

Hill, N. E. G. (US) Prepared Comments on Oscillographic Recording Techniques as Applied to Flight Testing

Holloway, A. H. (UK) Standardization of Documentation Size and Format Abstracting Service

Hoover, G. (US) A Methodology for Aircraft Instrument Display Design—Uniterm System of Coordinate Indexing

Hucher (F) Essais de Dégivrage par Chauffage Catalytique

Hufton, P. A. (US) Flight Testing for Operational Requirements (with Driscoll)

Idrac, Jean (F) Prepared Comments on Measurement of Servo-Control Characteristics

Jackson, F. B. (US) Scientific Films

Kennedy, R. A. (C) Scientific Translations—Catalogue cards

Lachmann, G. V. (UK) Boundary Layer Control*

Lazzarino, Lucio (I) Airworthiness Requirements*

Lefebvre, Serge (US) Prepared Comments on Measurement of Servo-Control Characteristics

Lowry, W. K. (US) Research in Documentation

Lukasiewicz, J. (C) Development of Intermittent Wind Tunnel Technique

MacPhail, D. C. (C) Selected Canadian Problems in Aeronautical Research and Development*

Markham, J. R. (US) Some Aspects of Supersonic Wind Tunnel Operation

Marx, A. J. Prepared Comments on Measurement of Noise and Vibration in Flight

Meyer-Drees, J. (NE) Helicopter Rotor Flow Patterns*

Morant, G. (UK) Body Measurements in Relation to Working Spaces in Aircraft

Mullins, B. P. (UK) Diffusion Flames in the Laboratory; Documentation Problems in the Field of Combustion

Payne, R. B. (US) Factors Affecting the Validity of Aeromedical Research Data

Porter, George (UK) Flash Photolysis and Carbon Formation

Potocki, W. J. (UK) Subjective Experiences and Reactions During Flight Testing in the Transonic Region*

Rendel, David G. A. (UK) The Measurement of Atmosphere Icing Conditions

Rom, G. (NE) Subject Classification

Ruffel-Smith (UK) Discussion F.T.P. and P.

Shepard, H. A. (US) Some Studies of Laboratory Management*

Shortal, J. A. (US) Techniques of Free Flight Testing at NACA

Stefanutti, Sergio (I) Selected Italian Problems in Aeronautical Research and Development*

Stewart, W. K. (UK) Adapting the Aeroplane to the Pilot

Surugue, Jean (F) Definition of Technical and Scientific Terms in Combustion

Taube, Mortimer (US) Uniterm System of Coordinate Indexing

Timman, R. (NE) Methods and Results of Non-Stationary Airfoil Theory

Ulug, Fuat (T) Prepared Comments on Training Aircraft Development in the Turkish Air Force

Unsal, Huseyin (T) Prepared Comments on Training Aircraft Development in the Turkish Air Force

Valensi, J. (F) Review of Methods of Measurement of Dynamic Derivatives

Van der Maas, H. J. (NE) Aeronautical Research and Development in The Netherlands; Past, Present and Future*

Van de Vooren, A. I. (NE) Measurement of Aerodynamic Forces on Oscillating Airfoils*

Van Every, K. E. (US) Aerodynamic Problems of High-Speed Flight*

Van Wulfften Palthe (NE) Somatotyping

Vessey, H. (UK) Retrieval System (Documentation)

Vogt Lorentzen, Lt. Col. (NE) Cold Weather Problems*

Whillans, M. G. (C) Human Factors in Aircraft Design*

Yavus, Kansu (T) Training Aircraft Development in the Turkish Air Force

Yeager, C. E. (US) Subjective Experiences and Reactions During Flight Testing in the Transonic Region*

Fastest Humans—High-speed research pilots discuss transonic problems at AGARD conference. ***Left to right:*** **Squadron Leader W. S. Potocki (U.K.), Squadron Leader Neville Duke (U.K.), A. Scott Crossfield (U.S.A.), Dr. Th. von Kármán, Major Charles E. Yeager (U.S.A.), and Commandant Roger Carpentier (Fr.).**

Pilot Problems in Transonic Flight

Excerpts from Discussions by Research Pilots at AGARD General Assembly

*Commandant Roger Carpentier (France)**

In my opinion, transonic flight does not present any psychological or physiological problems much different than those presented by the characteristics of modern aircraft, that is to say, problems associated with extremely high speeds at high altitudes. I understand that the major peculiarities of transonic flight are due largely to aerodynamic difficulties that are encountered in that regime, and (therefore) if one could design an airplane that did not present such anomalies, flight in the neighborhood of the speed of sound would not present any unusual problems. . . . .

The objective of every aircraft constructor and operator is to achieve aircraft whose behavior does not vary when going through the transonic zone, that is to say, in which the pilot is not aware that he is passing through the sonic barrier except by reading his Machmeter. Unhappily such an ideal airplane is seldom realized. My own experience has been . . . closely connected with the research and testing of aircraft with the view toward eliminating the peculiarities of transonic flight. . . .

We will first consider inversion of longitudinal stability. This shows up as a tendency to dive as one enters the transonic zone, and develops quantitatively as a change of sign in the slope of a lift curve and as an increased load on the elevators in stable flight. The point in which this instability occurs depends upon the relative thickness of the wing and the design of the tail surfaces. This (instability) is a serious fault because it reduces accuracy of piloting, particularly in a fighter airplane during the phase of the attack just before firing and also in the adjustment of aim during firing. It is equally very disagreeable in formation flying and requires great concentration by the pilot, which is extremely fatiguing. This fault is all the more disturbing

* Translation by S.P.J.

because it is often followed immediately by a condition of hyperstability. Formation flying at speeds within the limits established by these two characteristics becomes practically impossible.

Secondly, consider "wing dropping." This is a rapid and sudden rolling movement that appears in the region Mach 0.90 to 0.95. Because it is not always acceptable to limit an aircraft to speeds below that of the appearance of this phenomenon—particularly, since at Mach Numbers a few points higher, an airplane again achieves its normal stability in roll—designers are inclined to adjust the dimensions of ailerons so that it is possible to pilot the airplane correctly in this region with relatively small aileron displacement. This is always possible—it is only a question of control surface area and loads on the control system. In any case, the problem is complicated because it is also necessary to pilot the airplane satisfactorily in other regions of flight with the same ailerons. If the dimensions of the ailerons are made large enough to prevent wing dropping in transonic region, it is generally found that they are too effective in the other regions of flight. It is therefore necessary to effect a compromise that will be satisfactory throughout the entire range.

Third, consider the variation of elevator effectiveness. As a matter of fact, every control surface placed behind a fixed wing loses its effectiveness as the speed of sound is approached. On this point I believe that it is the loss of efficiency of the elevator which is the most disturbing. It is very evident that this reduction in efficiency (which in certain cases can lead to total inefficiency) is strictly unacceptable in flight maneuvers. Of all the solutions that have been envisaged to remedy that situation, the one that is called the "flying tail" is certainly the most satisfactory. This leads to the thought that similar solutions might doubtless be found for other control surfaces. The tests on special ailerons conducted in Great Britain for the Sherpa airplane perhaps have some connection with this same problem.

Fourth, let us take up the problem of directional stability. I think in this connection one can expect almost anything in transonic flight. The loss of efficiency of the rudder is well known. It becomes even more (important) when one takes into account inversion effects. I cite the example of inversion of ailerons due to the aeroelastic distortion of the wing, which is not, properly speaking, a transonic phenomenon. Some of you have seen, in the film "The Sonic Barrier," an outstanding case of reversal of effect of the elevator. Squadron Leader Neville Duke, who is here today, may perhaps be able to tell us if this phenomenon has actually been enountered, or if it is only a cinema effect. Personally, I have never encountered it. The most striking reversal that I have ever met with is inverse induced rolling. That is to say, a rudder displacement in one direction induces a rolling movement in the airplane in the opposite direction.

This phenomenon appeared one day while making some tests at high Mach Numbers with an airplane not equipped with servomechanisms on the ailerons. I tried to hold the wing horizontal with the rudder alone, but I then found that beginning with a certain Mach Number it was necessary to change the direction of my foot action to correct the transverse displacement. This phenomenon is, moreover, reasonably well known. The late lamented John Derry had already discovered it on the de Havilland Swallow. All such anomalies must naturally be combated with the greatest possible energy, otherwise flying high speed aircraft becomes work for a juggler.

In the realm of directional difficulties should be included the violent variations in rudder loads which have led to the adoption of servomechanism controls by every country. One could get into endless discussions on ways to provide a natural "feel" to the pilot through the servomechanisms. . . .

Up to the present my discussion has been aimed toward the aerodynamic rather than the physiological phenomena. As I said in the beginning, if it is considered desirable that the pilot be at ease during transonic flight, it is necessary above all to eliminate any unusual behavior of his airplane in that regime of flight. I cannot close without mentioning one point from Dr. Whillans' lecture. I am entirely in accord with him when he says that the cockpit in a modern airplane resembles more the design of a humorist than a well thought-out ensemble. Although considerable efforts at standardization have been effected, I believe that there is still much to be done. Several days ago I was driving on the highway and I noticed that, without taking my eyes from the road, I could read my speed perfectly from the instrument board. Is it necessary for us to conclude here that we are lagging behind the manufacturers of automobiles in that particular area?

Squadron Leader W. S. Potocki (U.K.)

In my opinion, these psychological and physiological problems seem to appear mainly when flying aircraft that, while not suitably designed or equipped, are worked to their limits in the high transonic range. The new generation of aircraft incorporating the results of more recent achievements in the aerodynamic science appears to suffer very little from these shortcomings. They have, however, different associated complications, which, while barely existing in transonic range, present the pilot with other factors and may become the psychological and physiological problems of truly supersonic flight.

I think, therefore, that, for the purpose of our discussion, I should divide the aircraft into two categories:

(1) Transonic vehicles manually controlled or fitted with low boost assistance which, while stressed to withstand loads imposed on them in that region, are limited by their aerodynamic performance whatever its cause, and

(2) The vehicles designed for supersonic penetration which, as a result of aerodynamic "cleanup" and other

refinements, present little problem in control at the transonic range.

Flying, as any purposive action, implies foresight and is governed or directed by provision of its effects. More so test flying, but here the effects cannot always be predicted with high degree of accuracy. It is at this juncture when the "unknown" emerges. This unknown may be faced differently by various individuals. Some may welcome it as a means of self-assertion; some others as a fulfillment of curiosity or of creative instinct; some others may decline its acquaintance altogether. If they decide to meet it, regardless of the reason for this decision, they must at times come up against the instinct of self-preservation, this great inhibitor of action.

If action is to be forthcoming in the consequent venture, the instinct of self-preservation must lose its importance and become secondary, however much in attendance.

The psychological aspects of transonic flight constitute a problem mainly when the unknown is being explored. Once facts are established, the repetition is in the realm of knowledge, or at least experience, and enters the field of intelligent adaptation. The growth of particular experience leads to more confidence and finally to full mastery. When flying aircraft with manual controls in high transonic range for the first time, to the limit of their aerodynamic possibilities, a feeling of tension, arising probably from the aforesaid instinct of self-preservation, manifests itself in a degree and is proportional, I should say, for example, to the angle of dive one has to do to reach the limitation and to the associated uncertainty regarding the power of recovery. The loss of control effectiveness and unpredictable behavior in longitudinal and lateral planes with the increase of Mach Number, coupled with unfavorable trim change due to air brakes if they have to be used, are, I think, the worst offenders. Any nonlinearity in control behavior such as snatching and twitching or oscillatory motions such as buzzing all suggest abnormal conditions of control and are detrimental to morale. The loss of rotary damping in tailless aircraft, because of its short period, in connection with the increase of hinge moments on conventionally aerodynamically balanced controls, is a difficult condition to master, as one is not able to arrest the sympathetic motion of the elevator in the oscillation and must resort to fall in Mach Number for recovery. The belief that an unstable motion of this kind may result in structural failure before there is time to slow down makes it quite a difficult proposition in sustained dives.

Any severe instability in maneuver, whether stick free or fixed, when encountered at transonic speeds, is very unpleasant, because it is practically uncontrollable and again depends on fall of Mach Number for recovery.

The physiological aspects in the case of manually controlled aircraft in transonic range I should limit to the abnormal increase in hinge moments. This hard manual work on the border line of satisfactory oxygen conditions (a low cabin pressure differential or complete lack of pressurization) makes heavy demands on the pilot. The above conditions may be aggravated by nonfitment of g protective clothing thus increasing resistance to fatigue and giving rise to possibilities of mild anoxia. As a result of some uncontrolled development in the conditions of flight, the time involved in recovery may result in subconscious holding of the breath or, conversely, overbreathing, which may, in the former case, produce a mild anoxia, or, in the latter, a possibility of CO_2 washout. This CO_2 washout condition, known in America as hyperventilation, may produce dizziness, or disturbance of vision, or faintness. In the case of highly boosted or fully power controlled aircraft designed for sonic penetration, the aerodynamics of transonic flight give little cause for anxiety, unless, of course, the engineering side of the power controls displays some form of imperfection. With power controls with manual reversion, however, which, in my opinion, is always desirable, this is not so. These are still in their infancy from the point of view of acceptability of control in manual flight at high transonics. Although the introduction of automatic trimmers for reversion to manual does improve matters to a certain extent, nevertheless, it brings in a possibility of the autotrimmer runaway case at the instant of change-over. This, although very unlikely from the point of view of academic probability calculations, is possible and adds an unfavorable factor to the pilot's psychological set.

The power controls, with consequent superimposition of power units between the hands and the control, deprive the pilot from detecting instantly any irregularities taking place at the control, irregularities that may be caused by the power unit itself. Any unusual vibration or buffet draws one's attention to the possibility of flutter, unless it is known that the control is truly irreversible.

The physiological problems at transonic range, in the high performance fully power operated aircraft, appear to me to be less acute, unless the reversion to manual is necessary and particularly if this happens to be operationally unacceptable in that range. It is then that the hard work begins again. If, however, full efficiency of equipment is assured to include pressurization, power operation, and g protection, few or none of the usual problems previously mentioned are in evidence, the lack of comfort and the restriction in bodily movements being the most apparent penalty. The low altitude transonic flight experience is predominantly Squadron Leader Neville Duke's domain, but from my experience, I would like to add that I found turbulence at high indicated air speeds fatiguing if the flight was prolonged and the aircraft's response to gusts high, as in the case of the small Delta type of aircraft with comparatively low wing loading.

Squadron Leader Neville Duke (U.K.)

I am struck by the extreme similarity between Commandant Carpentier's paper and mine, because it is almost word for word the effects that we have noted in England on aircraft at near sonic or transonic flight, so

that I need not take up your time with any comments I have on that, except to confirm that the reverse sign of rudder has also been experienced by us, and it would probably appear to be quite a common feature, perhaps tip stall on one wing, causing a wing drop; and by using opposite rudder you stall the other tip when the wings become level again. Regarding the psychological and physiological aspects—I think my friends here and myself are evidence that there are no psychological difficulties. We all appear to be fairly normal people. It was interesting to hear from Dr. Whillans that the pilot's days of usefulness are to be so short, and I would hotly contest that we will be effaced by the guided missile. I think there is no doubt that the guided missile will come, but it will be a long time before it is entirely controlled from the ground, and there will be a pilot in the machine at least monitoring the equipment and also making the final attack. Such equipment can always be jammed by the target. If the pilot has a view of the target, nothing can stop him from going in if he has the determination to do it. There must not be any likelihood of failure to intercept aircraft in a small country like England where a small number of atom bombs would do a tremendous amount of damage.

However, I do support this plea for simplification, but not quite in the same way. He would have preferred to put in much more equipment to make the pilot's task easier, and I would suggest that the pilot is quite a capable person and does not necessarily need automatic devices that weigh a tremendous amount. He would far rather work harder than he does now and have the increased performance by the lighter load he would have to carry. Regarding power control and feel, it is always a great question in the pilot's mind deciding what type of feel he would like. Certainly, on an aileron, a simple spring feel appears to be satisfactory, and it is interesting that a number of flights have been made without any feel at all on this control, and it has not been too adversely commented upon. No doubt for instrument flying or bad weather conditions, you would need some artificial feel.

I think, also, the time has come when an aircraft must be designed for the particular role for which it is intended. Taking the fighter class of aircraft: To expect a machine to perform satisfactorily for interception, high altitude flight, and ground attack as well is asking rather a lot and places quite an unfair burden on the designer. I would like to refer to the type of fighter we are primarily concerned with in England—the interceptor fighter, where performance is the primary requirement. Climb and acceleration are probably the most important, as well as top speed and maneuverability. In that type of machine, the endurance will probably be an hour in which the designer can note that there will not be a need for any relief tube, which I believe is still in the requirements. He will also accept some discomfort or quite a lot of discomfort for that length of time, providing that he knows he is thereby getting the improved performance due to weight reduction. . . .

Referring to the cockpit, I feel it must be as small as possible. I think a small compact cockpit is much preferable to a large cockpit, but this is again dealing with our local requirements in the United Kingdom where maybe the fighter endurance is not so great as would be required in the States for different tactical or strategical reasons.

I would still plead for rear vision to be provided in fighters. In spite of the fact that you may be traveling at Mach Numbers of 1 or 2, it is always the chap who creeps up behind who is the most sinister fellow to cope with, and, although you may be traveling very fast, relative speeds aircraft to aircraft are still going to be no greater than they were several years ago. If sight cannot be provided to get you on to the target—admittedly the turning radius will be such that you will be out of sight of one another in a circuit—there must be some adequate artificial means provided, because, of all the senses you have available on the ground, the only one that does remain to you in the air is sight. On the instrument presentation—to touch briefly on one or two points which I think are interesting—the most dangerous instrument now in the aircraft is the altimeter, because the rates of descent involved are some 60,000 ft. per min. and make it quite impossible to take an instantaneous reading of the altimeter, which is rotating very rapidly, and, even in test work where you are setting off at a particular height in a dive, I find it easier to recover or pull out on ASI readings rather than rely entirely on an altimeter.

The artificial horizon, again, is another disturbing instrument when high angles of bank are needed for sustained periods, in even modest turns at high air speeds.

Pilot's personal gear was mentioned, and the number of connections he has joining him to the aircraft ought to be deplored, and I think that does give rise to some concern when flying at very high altitudes where pilots appreciate the dangers that may beset them if oxygen failure occurs. When scanning rearward, there is always the danger of pulling out the oxygen connection by accident.

The protective crash helmet is a very desirable feature, provided it is made as light as possible. Because in turns where sustained g of probably 6 is not unusual to expect in combat, you are not only sitting bolt upright but are leaning forward slightly and perhaps looking around at the same time, and the weight of that helmet can be quite a strain to hold up.

To touch on high altitude and low altitude points, separately, the problem besetting the pilot is quite appreciable, because at 50,000 ft. you would survive for 10 sec. without pressure even using full oxygen, and we are told that at 60 or 63,000 your blood will boil, and if you succeed in getting to 70,000 ft. you will suffer from ozone gas, so it is obviously a tremendous problem, since those heights are really only scratching the surface. The essential pressure suit for use above 50,000 ft. has need of development. I am not actually familiar with the latest developments, but the one I have been

familiar with is a most uncomfortable device if it has to be inflated.

Survival was mentioned at high altitude, and it would seem that the capsule would offer the only reliable solution, if you could be sure of jettisoning the device without causing any large pitching moments or effects which would be detrimental to the pilot.

Normal vision at high altitude: Above 45,000 ft. it seems that 4 or 5 miles is the maximum you could probably pick up a target without some assistance from radar or an artificial means. Although goggles or visors can counteract these effects, they may mist up and detract from your vision.

Sunburning also has been experienced at high altitudes, which may be important to the bomber crews.

On fatiguing points, I think a number of dives over a short period of time, from high altitude of 40 or 50,000 ft. to low altitude and up again, has been found to be particularly fatiguing, probably due to the very high rate of descent involved and consequent change in pressure.

At low altitude, G-suits are essential for combat purposes, and it is there that the aircraft performance cannot be used fully, because the pilot cannot withstand the high acceleration of which the aircraft itself is capable. Breaking strains of 12g are available, and the pilot is probably limited to $7^1/_2$g, even using a G-suit.

Navigation at low altitude presents a difficult problem. At 600 m.p.h., I think 5 deg. off track can cause 5 miles error in position in 5 min., 1 mile in 1 min.

Cabin heating and conditioning are also important not from any luxury aspect, because, as mentioned before, the pilot is not asking for any great comfort even if his years are numbered; he prefers to be uncomfortable and get the effective performance, but cabin conditioning and heating are obviously essential.

I think that is all I have to say, but, as requested, I would like to clear up this point, perhaps, on this reversal of elevator forces at h'gh Mach Numbers depicted in the film which has caused so much controversy. I understand that they did actually get it from aileron reversal, which is not too uncommon a feature, but decided to transfer it to the elevator to be more readily understood by the layman thinking that there was some authenticity in the case. If you have a flexible fuselage subject to aeroelastic distortion and apply up-elevator effects that induce a tail load, causing a change in tail plane incidence, the airplane will actually go into a dive, so I think there was some reason for it.

*Major Charles E. Yeager (USAF)**

The biggest problem in flying an airplane that is used strictly for research is being frightened. You may not think a pilot gets scared or is worried about the end results. That is the biggest problem facing you, especially just before the flight.

One of the first things you run into in our type of research airplane or the rocket is the abnormal way at which you get started on a flight. In order to conserve the small amount of propellant that you have to give you power, the airplane is taken up to 25 or 30,000 ft. and released from a mother airplane. . . . After the combination of two airplanes has gotten up to 10,000 ft. . . .you go back into the bomb bay of the mother airplane and climb down into the cockpit of the X-1. It is very cold. You are wearing a pressure suit, and the pressure suits that we have are extremely efficient, but they are extremely uncomfortable. . . .

You are buttoned into the research airplane. You have about 35 or 40 min. during the climb to use your check list, set up all of your pressures, turn the various switches on that you will need after drop. You are continuously checking your oxygen supply and the communications and doing various other jobs during the climb.

As the moment of release approaches, the anxiety naturally increases. Just prior to drop when the bomber pilot starts to count down for release, you start tightening up a little bit. You start breathing faster and start leaving your fingerprints on the stick. When the count-down is finished and they pull the lever that releases you, things start smoothing out, as far as the feeling of the pilot is concerned. You usually fire off one, two, or three of the rocket chambers, and as you gradually start picking up speed, the pilot starts calming down. You are occupied with doing a job, and, actually, you don't have time to think about being scared. You start smoothing out a little bit.

The characteristics of the X-1 and the X-1A when going through the transonic region are practically the same as Commandant Carpentier and Neville Duke described for airplanes such as the Mystère and the Hawker Hunter when passing Mach 1. You invariably pass into a small region of buffeting, and you get a wing drop that you counteract with both rudder and/or aileron. Once the airplane becomes supersonic things start smoothing out, your controls become normal again, the airplane flies very smoothly.

Here you begin to face new problems. At high altitude you start getting into a region where you are depending upon mechanical things to keep you alive and, if they fail, you go to the suit. If you have to leave the airplane, you are exposed to very low temperatures during the long fall back down to where you can use your parachute. Also, since airplanes with rocket-type propulsion have very high performance and very high rates of climb, you must start flying in a path such that will bring you level at the altitude where you want to make your run. Fifty to 60 sec. prior to the time you want to level out you must start the push over gradually. . . . Sometimes you can roll the airplane into the inverted position and hold 1g so that you have a normal feel. But that penalizes your performance, so, most of the time, it is a gradual push over where you are holding almost 0g's as far as the vertical and lateral axes of the

* These remarks were made extemporaneously.

airplane are concerned. You are then under an abnormal condition, your feelings are not what they should be. You seem to be floating. You have a tendency to overcontrol both laterally and longitudinally. Also, as you are picking up speed, the airplane goes through various trim changes due to the unsymmetrical construction of the wings. Then you start worrying about getting back toward your point of landing!

We have flown at speeds $2^1/_2$ times the speed of sound, or around 1,650 m.p.h. There is no difference at flying at that speed, as far as the pilot is concerned, than there is at flying at 50 m.p.h. or 1,000 m.p.h. if the airplane responds as it should. . . . A pilot has no sensation of speed. The flying of the airplane is perfectly normal. On the way back down, as you decrease your speed you run into the same phenomena of getting a wing roll and buffeting. Finally, since (at Edwards Air Force Base) we have a very large lake bed to land on, we have no problem of getting the airplane on the ground. Although all landings are dead stick, we have a little over $7^1/_2$ miles of runway, and even when we do overshoot or undershoot a couple of miles, it makes no difference.

I will leave research planes at this point and go into what I would like to see in a fighter. . . . The many accidents that are caused by poor cockpit design and instrumentation is rather obvious. That is where the pilot does his job, and when that airplane is a fighter and it is designed to do one job, the cockpits could all be alike. On all the airplanes that we fly today, all the landing gear handle does is raise the gear or lower the gear. Yet, of all the fighters made, every landing gear handle has a different shape, a different size, and a different location, and I could say the same for the flap handle, the control column, the throttle, and other components.

In the old days, when we built a fighter like the Spit or Hurricane, or the Mustang, or the Thunderbolt, we built an airplane that could take more than a pilot could. If a pilot pulled as hard as he could on a stick, the airplane was heavy, and you had no boost controls so you could not pull the wings out of it.

Today, we have airplanes that will fly 6, 7, and 800 m.p.h., which will be used for combat. They have irreversible controls or 100 per cent boost, so a pilot can break up any airplane. I am all for specializing the fighter-type airplane, especially when it is to be used for high altitude interception. Since it will be doing its job at high altitude, the airplane should be designed to save weight and give it better performance, to a load limit of, say, 4 to 5*g*'s, with an ultimate of maybe 6. The weight of this airplane could be cut almost in half as compared with one designed for a breaking point of, say, 12*g*'s. (If the pilot wants to pull more than 5*g*'s, put a pistol in the cockpit with instructions to land and shoot himself. At least we can save the airplane!). . .

It is my opinion that, although we try to make things simpler for the pilot, he can adapt himself to almost any condition under which you put him. We would at least like to have enough jobs to do in the cockpit to keep from getting bored or going to sleep! Small things like computing fuel consumption into time of flight remaining keeps one awake sometimes. . . . As Neville Duke said, we will sacrifice a lot of conveniences for performance, which is what we are looking for anyway.

*A. Scott Crossfield (NACA)**

Listening to the people here this week I have thought that I would almost rather be on the aeromedical side of this business than the stability and control side. Mr. Carpentier virtually dissolved the pilot's problems if we get rid of the stability and control and aerodynamic problems or, at least, find better than present solutions. Mr. Duke referred in many instances to extending subsonic airplanes through transonic and into supersonic regions for which they were never designed or built. This capability was mainly due to the capability and adaptability of the human aviator who is apparently on trial here against the automatic devices. The problems the pilots speak of are engineering problems. The aeromedical problems are truly medical and, apparently, do not receive their warranted attention.

This automatic device thing needs some thought. I will speak only with regard to the research airplanes. Research airplanes are, of course, designed for one purpose only. One of the first things that we are faced with to make them useful—even to get them into the air—is to strip them of as many nonpilot operations as is practicable and put manual control in the cockpit for the pilot to monitor and operate. This gives the pilot an opportunity often to save what would otherwise be a lost flight by making minor adjustments in the rocket, jet engine, or electrical systems. It pays us back even more in the thing we have been fighting for all these years—performance. . . .

Our problem there is simply thrust and drag. With drag, we tie the weight and complexity of the airplane, and on thrust—just as fast as we can make engines of greater thrust, we make them. Again this automatic device thing comes into the picture, particularly under combat conditions. With automatic limiting devices like *g* limiters, engine r.p.m. limiters, and rocket engine thrust limitation, the pilot cannot draw on that little extra ounce of luck that might be stored in the engine by the engineers to get himself out of a jam by pulling a few more *g* (a calculated risk) or by getting a little more speed, a little more power, or a little more thrust.

To exemplify, the total flight instrumentation that I use in the D558-2 are needle, ball, air speed, altimeter, Machmeter, and accelerometer. The rest of the flight instruments have been taken out as extraneous, even though the flights call for very precise operations and are largely done on instruments. In place of these we have put in more gages and manual controls to operate the various components of the rocket engines. A malfunction or failure might be catastrophic, and such in-

* These remarks were made extemporaneously.

(*Continued on page 87*)

Compressor Bleed in Turbine-Powered Aircraft

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(I) Introduction

Compressor bleed is a convenient means of extracting a flexible form of motive energy from the main engines of turbine-powered aircraft. It is, in fact, so flexible and adaptable that the designer's choice of where to use it, and where not, is in itself a difficult one. In its earliest form, compressor bleed was used for its most obvious function, that of supplanting a separate cabin pressurization compressor. The F-80 aircraft was one of the first to use this form in combination with the first application of the air turbine for cockpit refrigeration. The simplicity of this early installation is evident in Fig. 1. Note that other functions requiring application of small bleed flows were included in this system.

Gradually, in later versions of this type of aircraft, additional functions requiring larger flows of bleed air were found. These included afterburner fuel pump operation, airfoil and windshield anti-icing, and others. As multiengined jet aircraft were developed, the number of applications for this form of energy grew, and the concept of low-pressure pneumatic power gradually became recognized as one of the major types of auxiliary power among those already in general use.

Engine development trends have had a major bearing on the application of low-pressure pneumatic power. In their earliest form, the engines were generally of the single-stage radial compressor type, and pressure and temperature ratios were very moderate. In fact, the problem of conserving the heat of compression amply to heat the cockpit was a very real one. The low pressure ratio, when applied to a simple nonregenerative type of cooling turbine, generally did not involve any such problems as excessive fogging or freezing in the turbine discharge air supplied to the cockpit. Since airplane speeds were well below sonic, the problem of aerodynamic heating was also moderate. Bleed air quantities in these early systems were small, generally not exceeding one-half of 1 per cent.

As engine design and performance and, correspondingly, airplane performance have improved, many new problems have arisen. Radial compressors have been almost entirely replaced by multistage axial flow types. Pressure ratios that were formerly 3 or 4 are now 10 or 12. Fig. 2 compares compressor discharge pressures, including ram, at typical air speeds for early engines and present-day engines. Compressor discharge temperatures that were about 400°F. are now as high as 700° or 800°F., as evidenced by the comparison shown in Fig. 3. The turbojet types of engines are now being designed for very large airflows, both total and per unit of frontal area, resulting in higher propulsive efficiency. Fig. 4 shows a comparison of early and present-day engine airflows. The large flow increase, of course, means that a given quantity of bleed air represents a smaller percentage of the total.

In the turbine-propeller type of engine, however, the need of high airflow for high propulsive efficiency does not exist; on the contrary, the highest cycle efficiency corresponds to the highest possible temperature and pressure ratio across the turbine and, therefore, the minimum quantity of primary airflow per unit of shaft power output. Fig. 5 shows a comparison of engine airflows for a typical turboprop and turbojet engine at the same power output. In the turboprop installation, therefore, the total quantity of bleed air which is permissible is often marginal for the many new functions to which it can be applied. At the same time, the pressure and temperature ratios in the turboprop engine are as high as those of a high performance turbojet.

It is apparent that pressures of nearly 200 lbs. per sq.in. and temperatures of 800°F. are in excess of what can be efficiently utilized for some applications of bleed air. These conditions introduce extremely difficult problems in the safe distribution of this energy. It should be noted, however, that the quantity of bleed air required per unit of motive or heat energy delivered is minimized by using it at this high intensity level.

The obvious result of this distribution hazard is a search for a means of extracting bleed air at a lower energy level. This could conceivably be done by employing mid-stage bleed on a single-spool engine or interspool bleed on the twin-spool type. The divided or twin-spool type of engine is used to permit more flexible control of the difficult matching problem that exists between compressors and turbines of engines that are required to meet an extreme range of altitude and speed.

Mid-stage bleed is difficult to accomplish successfully for two reasons. There is first the problem of the limited physical space between blade rows for diffusing and turning this air without excessive losses. Secondly, the critical and sensitive nature of the aerodynamic matching problem between adjacent blade rows in an axial flow compressor would require that the bleed quantity be maintained within narrow limits during *all* operating conditions of the engine in order to avoid the propagation of a stall throughout a large part of the compressor. This second condition would, therefore,

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EARLY USES OF BLEED AIR

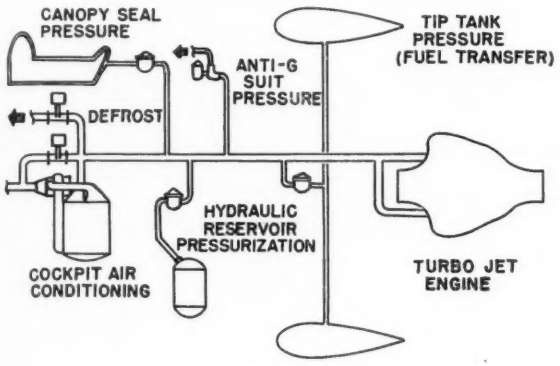

FIG. 1.

ENGINE BLEED PRESSURE

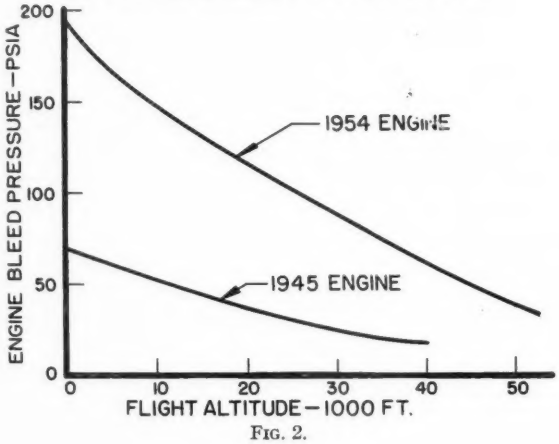

FIG. 2.

ENGINE BLEED TEMPERATURE

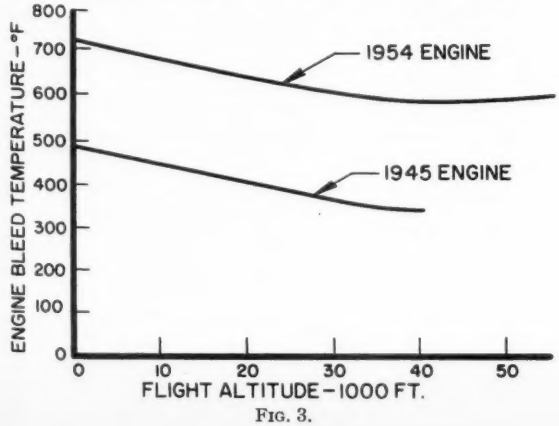

FIG. 3.

ENGINE AIRFLOW

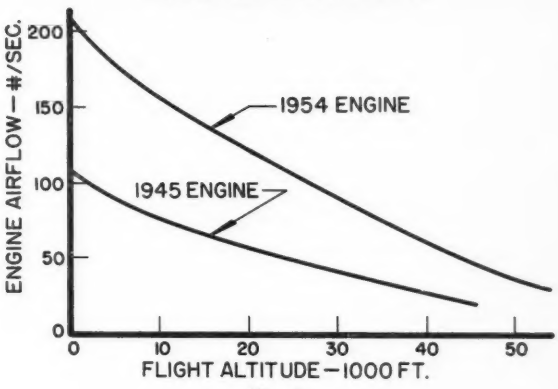

FIG. 4.

ENGINE AIRFLOW TURBO JET VS. TURBO PROP

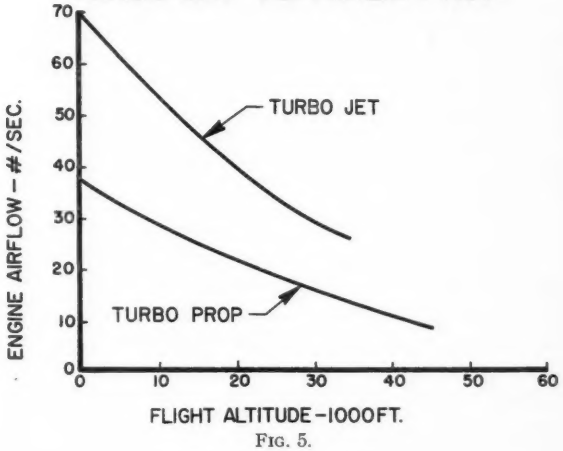

FIG. 5.

ENGINE BLEED PRESSURES LAST STAGE VS INTER-SPOOL

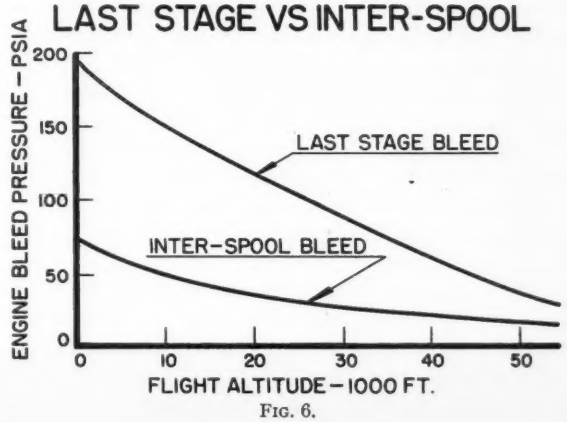

FIG. 6.

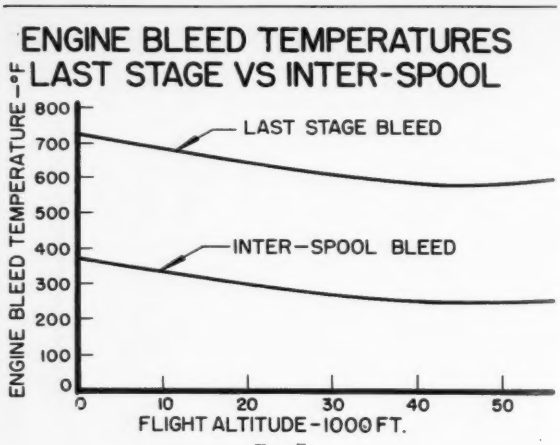

FIG. 7.

demand that the mid-stage bleed provision be designed for the maximum-required bleed quantity at the minimum-required engine speed and that, for all operating periods of the engine, this bleed quantity be diverted whether required or not. Last-stage bleed, in contrast to this, is usually accomplished in the low velocity section of the diffuser just upstream of the combustion chamber and is thus not a serious factor in the inter-blade-row aerodynamic balance.

It should be noted that mid-stage bleed has sometimes been resorted to as a means of easing the engine-starting requirements, but in this case good pressure recovery at the bleed ports was not an objective. Interspool bleed, on first examination, would therefore appear to be much less objectionable than interstage bleed because it could obviously be done in the transition passages between spools. Figs. 6 and 7 compare bleed pressure and temperature at the interspool ports with conditions at last-stage bleed ports of a typical engine. For some applications this method does satisfy operating requirements, but for certain important remaining functions the pressure limitations of interspool bleed fall short, particularly in high speed applications where aerodynamic heating is an important factor. It has been suggested that pressure deficiencies of interspool bleed can be overcome and its advantages retained by means of a booster compressor energized by a small quantity of either interspool or last-stage bleed air. Although this device might be compact due to the fairly high density of the air handled, justification for the method would hinge on the results of an overall system study.

The twin-spool compressor is a feature thus far found only in the turbojet field, and the possibilities it offers are therefore not available to alleviate the turboprop high-temperature and high-pressure bleed problems.

The maximum quantity limits on compressor bleed are generally governed by the operating temperature limits on the turbine wheel. As an increasing portion of the compressor airflow is diverted away from the combustion chamber and turbine, the latter must operate at a higher temperature in order to deliver the same compressor horsepower from the smaller quantity of combustion products still flowing through it. The resulting maximum external power available will be reduced also, whether it be jet thrust or shaft power. In most present engines the upper limit of bleed quantity is 5 to 10 per cent, and very few applications justify the severe penalty that this much bleed implies.

In the discussion that follows, it will be apparent that most of the attention is directed to bleed applications in multiengined aircraft. The obvious reason for this is that the bleed systems become much more extensive in the larger transport and bomber-type aircraft. However, bleed systems in single-engined aircraft will share a good number of the basic advantages and problems to be discussed.

(II) Bleed Applications

By means of air turbines (either fixed, partial admission, or variable angle nozzles), piston and cylinder actuators, or jet pumps, bleed air can be utilized to accomplish practically any auxiliary power function now energized by the other well-known methods—hydraulic, electrical, or mechanical. In addition, it can handle some jobs not at all suited to some of these other forms. It is also a direct and convenient source for large quantities of heat and airflow. It is not suited to certain tasks, as, for example, producing very rapid linear motion such as can be obtained by means of high-pressure (3,000 lbs. per sq.in.) pneumatic actuators or very high load linear motion, which can be obtained for landing gear retraction by means of hydraulic cylinders. Either of these latter forms can be energized at their source, however, by bleed air-driven pumps.

In order to appreciate fully the potential value of the low-pressure pneumatic system, the following outline of the numerous functions for which it can be utilized is presented. (Refer to Fig. 8 for a graphic illustration of some of these.)

(1) Air conditioning for personnel and equipment:

(a) Pressurization for personnel and, where required, equipment.

(b) Heating for cabins, cargo spaces, and critical equipment items as well as defogging of windshields.

(c) Refrigeration, either of air-cycle or vapor-cycle type, for cabins and equipment compartments.

(d) Ventilation of various equipment areas by means of turbine-powered fans or ejectors.

(2) Ice protection:

(a) Thermal anti-icing or cyclic deicing of air-frame components, such as wing and empennage leading edges, scoop lips, ducts, masts, windshields, etc.

(b) Thermal anti-icing of engine inlet components.

(c) Deicing by means of pneumatic boots inflated by bleed air pressure and deflated by bleed air-operated ejectors.

(3) Engine starting:

(a) Air turbine starters, bleed operated for multi-engined aircraft.

(b) Air turbine starters, operated by bottled air for first- or single-engined starting.

(4) Auxiliary power generation:

(a) Constant frequency alternators powered by air turbines.

(b) Direct current generators driven by air turbines.

(c) Hydraulic pumps powered by air turbines.

(d) High-pressure (3,000 lbs. per sq.in.) pneumatic power compressors driven by air turbines.

(5) Fuel pumping by means of air turbine-driven pumps.

(6) Fuel tank pressurization by cooled bleed air for fuel transfer to the main tank and prevention of negative pressure in tanks during rapid descent.

(7) Boundary-layer control by means of bleed-operated blowers or ejectors.

(8) Direct mechanical actuators for functions such as tailpipe nozzle area control.

(9) Reverse thrust actuation by jets of bleed air.

(10) Motive power for small control functions, such as cabin temperature or pressure regulation.

(III) Problems of Compressor Bleed

The list of functions that can be accomplished by engine bleed air is long and the advantages are many. Before discussing the functions in more detail, it is appropriate to look at some of the major problems encountered by extracting compressed air from the engines and distributing it to various parts of the airplane.

Extraction Losses—Thrust and Fuel Penalties

The losses in engine thrust and fuel economy are generally greater per unit of air horsepower extracted by a bleed air system than those associated with direct mechanical power extraction. This is perhaps due to a mismatch of the engine compressor, turbine, and jet nozzle, occasioned by the extraction of compressor discharge air. Air extraction tends to increase the engine compressor flow and decrease the flow through the turbine and jet nozzle, and these changes in a fixed turbine and jet nozzle system cause a reduction in overall engine efficiency. Fig. 9 illustrates the relative specific fuel consumption increase of bleed extraction and mechanical power extraction. The example is based on the same power extracted by both means, and assumes that 100 per cent of the bleed air energy is

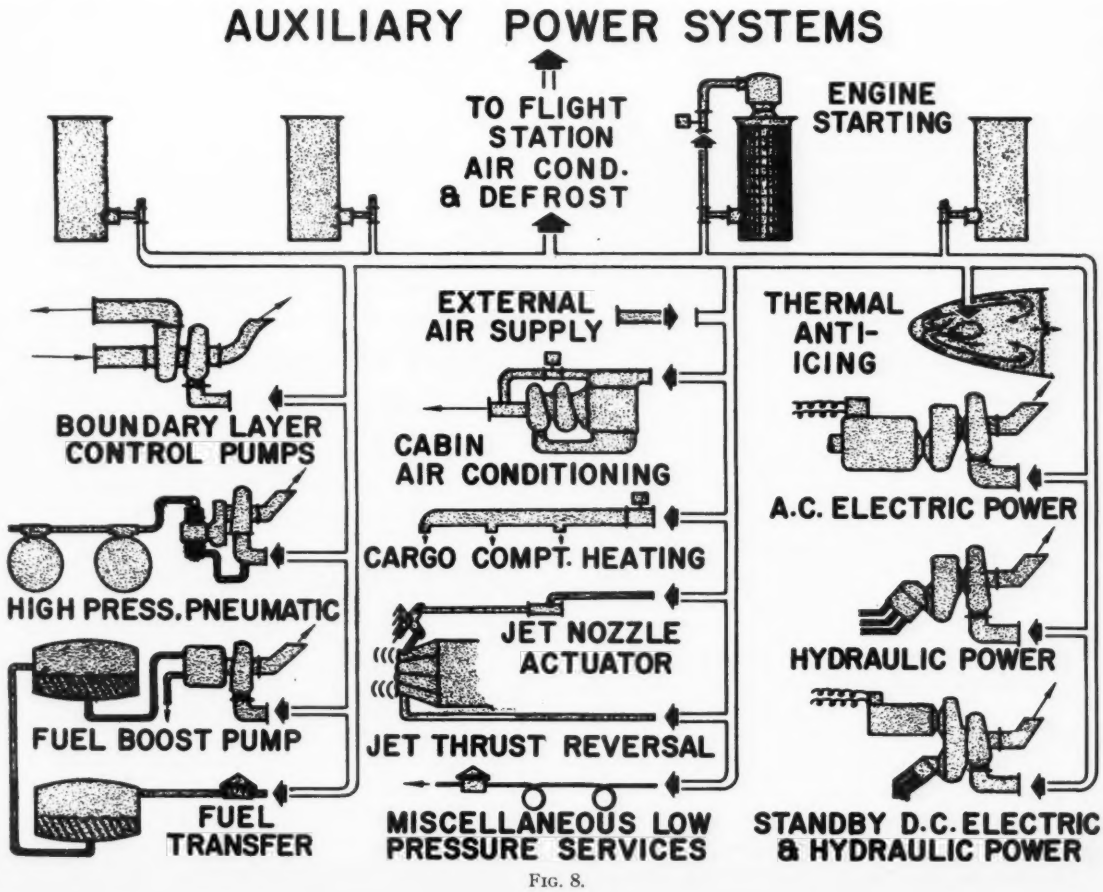

Fig. 8.

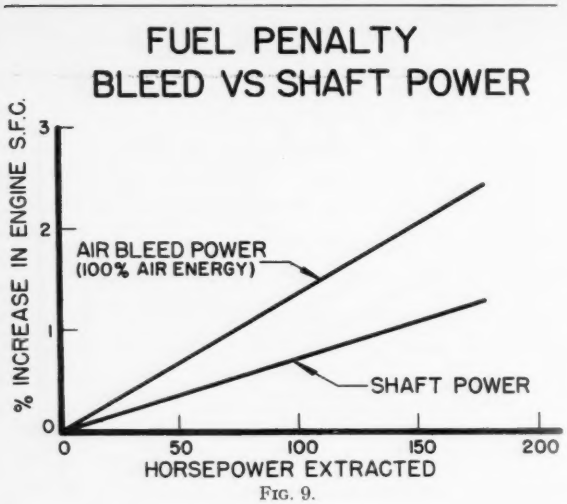

FIG. 9.

available. Actually a further power loss is entailed in the bleed air system because, at best, only about 80 per cent of this energy can be realized at the shaft of a high efficiency drive turbine. The available energy is still further reduced by unavoidable duct temperature and pressure losses.

The engine fuel control plays a large part in determining the thrust and fuel penalties caused by bleeding the engine. A turboprop engine is less affected by a given percentage bleed than a turbojet, because the propeller of the former provides a means of automatically varying the load on the shaft and maintaining the same r.p.m. with or without bleed. Loss of r.p.m. reduces overall engine operating efficiency markedly and thus contributes in large measure to the cost of bleed. It is, therefore, generally more economical to increase the throttle setting to compensate for bleed extraction rather than accept the greater losses attendant upon operation at reduced power and r.p.m. A throttle increase, however, causes an increase in turbine inlet temperature and a reduction in engine life. Also, if the engine is to be cruised at its normal maximum rating, no further throttle increase is available without exceeding engine temperature limits. For each airplane and engine combination, therefore, the fuel penalty due to a given percentage of bleed will be different and will depend upon the degree of throttle compensation available. Fig. 10 shows the result of various ways of handling the overall fuel penalty due to bleed. These curves show the additional take-off fuel load required for various continuous bleed rates in a particular four-engined jet transport on the North Atlantic crossing. For bleeds greater than .1 per cent of the engine airflow, the minimum fuel penalty is realized when the throttle is increased so that air speed and altitude can be maintained the same as they would have been with no bleed. The two constant-throttle curves show that, at high bleed rates, it is more economical to reduce altitude and maintain air speed than reduce speed and maintain altitude. At bleed rates below 1 per cent of engine airflow, the constant-throttle, reduced air-speed curve shows the least penalty of all three and seems to contradict the previous statement that increased r.p.m. is always more economical. These curves, however, reflect not only engine characteristics but also those of the airplane, and in this case the airplane characteristics were apparently predominant.

It is significant that the bleed flow required for cabin air conditioning of the airplane used in this example is less than 1 per cent of engine airflow. Therefore, the take-off fuel increase required for cabin air conditioning is less than 2 per cent, as indicated by Fig. 10. A change in fuel consumption of this order of magnitude can easily be lost in the tolerances of the engine and its fuel controls, and thus would be difficult to verify experimentally. Therefore, in aircraft where a continuous supply of bleed air is considered for cabin air conditioning alone, it is somewhat academic to compare its fuel penalty with that caused by other means of air conditioning, such as shaft-driven superchargers.

The fuel penalty for electric power generation by means of bleed-driven alternators in this airplane is about the same as that of the cabin air requirements, while total hydraulic power generation by bleed air requires somewhat less. If an extensive bleed system is provided to serve all three of these functions on a continuous basis, then the total fuel penalty becomes quite significant and must be carefully analyzed with regard to the design mission of the airplane.

Air Distribution

Referring once again to Figs. 2 and 3, it is seen that the duct system must be designed to operate at bursting pressures approaching 200 lbs. per sq.in. and temperatures up to 800°F. Obviously, it is necessary to fabricate the ducting of stainless steel or an equivalent high heat-resistant alloy to accommodate the temperature. Thin duct walls of the order of 0.020 in. can be used in ducts up to 6 in. in diameter because of the high yield strength of stainless steel in this temperature range. Sections of ducting are fastened together with Vee-band clamps, and leakage at the joints is minimized by

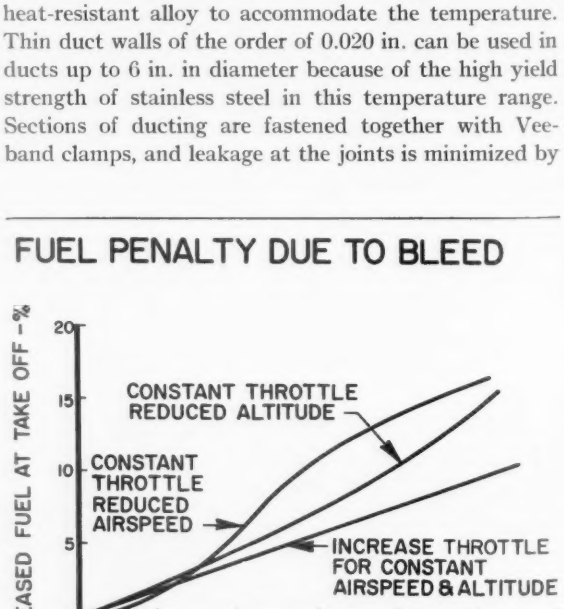

FIG. 10.

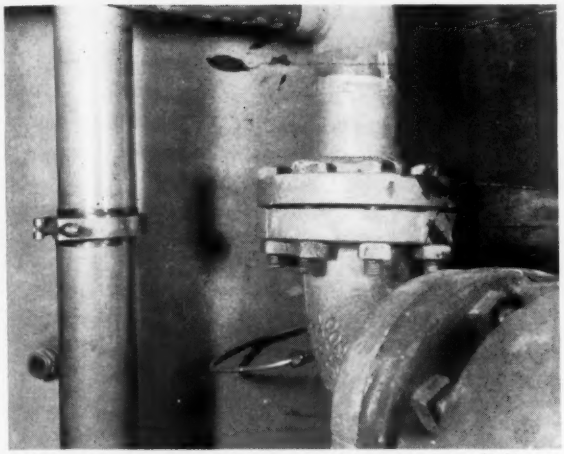

FIG. 11. Aircraft high-temperature duct and joint (*left*) and its industrial equivalent (*right*). Both ducts designed for 200 lbs. per sq.in. at 800°F.

metal gaskets. A typical section of this type of duct system is shown on the left-hand side of Fig. 11. As a matter of interest, the industrial equivalent of the high-temperature aircraft duct is shown on the right. Both ducts are rated at the same operating pressure and temperature, but the contrast in weight and bulk is evident.

Complications are introduced in the duct system when thermal expansion is considered. The large changes in relative temperature between ducts and air frame introduce linear deflections of the order of 1 in. in 10 ft. In order to provide relief for these deflections, flexible bellows or slip joints have been used in the duct, and swinging or sliding brackets have been used for duct support. Unfortunately, when under pressure, this combination of expansion joints and flexible supports exhibits all the characteristics of the classical pin-ended Euler column. The buckling tendency of the duct and the lateral forces at the supporting brackets are accentuated by the instability of the bellows when the latter are used for the flexible joints. The resulting behavior of a duct system so designed is best described by the colloquialism, "duct squirm." Examples of this behavior are shown in Figs. 12, 13, and 14. In Fig. 12, the bellows on the left has distorted into an *S*-shape, failing the support brackets on either side. The bellows on the right also shows signs of permanent distortion. Fig. 13 shows a similar bellows failure and shows clearly the damage to the hinged brackets. Fig. 14 shows distorted bellows and buckling of the duct caused by column instability.

The examples of failures shown in Figs. 12, 13, and 14 occurred on a full-scale duct system mock-up built to investigate these and other characteristics of a low-pressure pneumatic system. The mock-up is shown in Fig. 15. The squirm has been overcome in this particular system by the strengthening of existing brackets and the addition of more support points. The squirming tendency can also be overcome by the use of alternate forms of expansion joints, such as the pressure-balanced joint and the 360° and omega "steampipe" bends. Examples of these are shown in the sketches of Fig. 16. Obviously, the balanced joint is more complex and bulky than the simple bellows, while the "steampipe" bends are cumbersome but very simple.

Efforts have been made to improve the simple bellows by adding stabilizing restraints, such as external braid or internal sleeves. These restraints help considerably to keep the bellows in line, but the life of the bellows is reduced by the rubbing of the convolutions against the braid or sleeve. These, together with the fatigue life of the bellows when subjected to engine vibration, are not new problems but are, nevertheless, being investigated experimentally to ensure adequate structural integrity of the duct system.

Thermal isolation and insulation of high-temperature ducts are essential for obvious reasons. The surrounding load-carrying dural structure must be protected from local overheating and consequent loss of strength. High-temperature surfaces exposed to possible contact with inflammable liquids or vapors must be avoided. Much conflicting information has been published on the spontaneous ignition temperatures of such liquids as hydraulic fluid, engine fuel, and engine

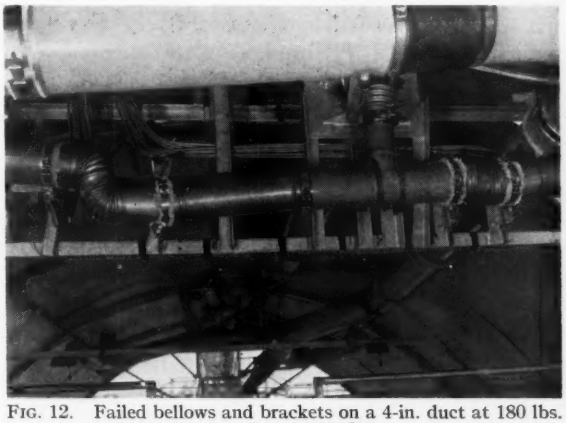

FIG. 12. Failed bellows and brackets on a 4-in. duct at 180 lbs. per sq.in. and 630°F.

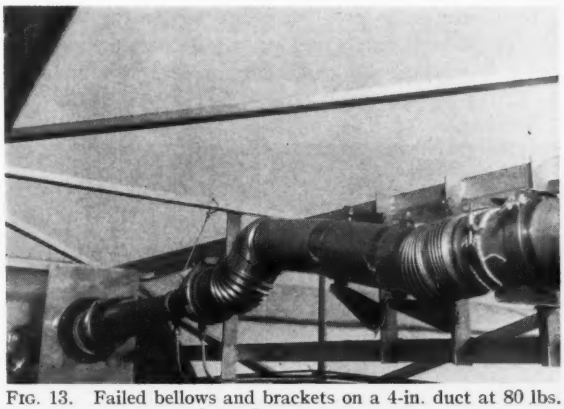

FIG. 13. Failed bellows and brackets on a 4-in. duct at 80 lbs. per sq.in. and room temperature.

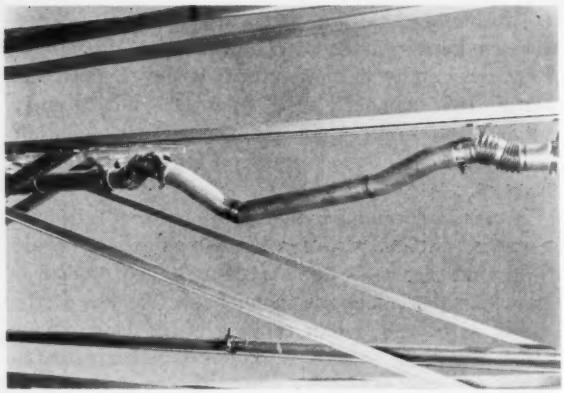

FIG. 14. Failed duct, bellows, and brackets on 2½-in. duct at 107 lbs. per sq.in. and room temperature.

oil. Most of this information has been gathered from tests in special laboratory apparatus that differs considerably from conditions existing inside the structure of an airplane. Preliminary testing under simulated airplane conditions has yielded encouraging results, but further investigation must be done to guarantee safety against fire from spilled or leaking fluids.

One way to avoid the difficulty of handling the high duct temperature problem is by precooling the bleed air just beyond the bleed port on the engine. Here the main disadvantage would be the large increase in amount of bleed air required for the delivery of an equal amount of energy. For example, if the bleed air were cooled from 700° to 500°F. before transmission to an auxiliary power turbine, it would require 20 per cent more bleed flow to produce the same power at the turbine. Cooling from 700° to 400°F. would cost 35 per cent more bleed flow, and 53 per cent more would be required if the air were cooled from 700° to 300°F. before use. In addition to the increased bleed consumption there would be an appreciable drag penalty caused by the ram air ventilated precooler. For the air-conditioning function, precooling is actually beneficial in most flight conditions, but for any power generation or thermal anti-icing functions, the loss would be severe, not only in terms of increased bleed requirements and cooler drag, but in size and weight of ducting.

In the same way, problems of excessive pressure might be avoided by a simple pressure-regulating device at the bleed port, but the throttling process would entail inherent inefficiencies in power generation and increased bleed flow requirements.

FIG. 15. Mock-up of prototype bleed air system for proof and functional testing before installation in aircraft.

It is conceivable that the potential hazards of an extensive hot duct system might be reduced considerably, without great fuel penalty, by a combination of precooling at the bleed port and reheating by combustion at the auxiliary power turbines. This system would at least isolate the high-temperature problem to local areas, and, because higher turbine inlet temperatures would be employed (up to 1,500°F.), the overall fuel economy would match that of uncooled bleed air. Increased weight of the drive turbine installation, due to higher operating temperatures and fire shielding, might be largely offset by a lighter supply duct system.

(IV) Discussion of Bleed Applications

Air Conditioning—Direct Bleed to Cabin

The most significant advantages of direct bleed air for cabin pressurization and air conditioning are a high degree of reliability and simplicity. A common bleed manifold connecting the compressors of a multiengined airplane provides an air supply that is uninterrupted by an engine failure. A pneumatic flow regulator, simple air-cycle refrigerator, and thermostatic by-pass valve provide an air supply system with automatic flow and temperature regulation. Separate flow and temperature controls can be used for different zones in the airplane, as, for example, the flight station and the main cabin. A schematic of the simple direct bleed system is shown in Fig. 17. Generally speaking, there is adequate bleed pressure available in all flight conditions to provide the necessary cabin refrigeration capacity, and there is more than adequate heat of compression available in all flight conditions to meet the cabin-heating requirements. In fact, it is usually necessary to allow the flow control valve to throttle the bleed pressure into the cabin refrigeration unit to avoid subfreezing temperatures, and it may be advantageous to provide a precooler to reduce the bleed temperature before entering the cabin flow and temperature control equipment. Reduction of excess pressure and temperature results in easing locally the duct design problem outlined in the previous section of this paper. This places great dependency on the reliability of the pressure and temperature reducing devices, a malfunction of which could cause a duct failure.

Currently, the outstanding disadvantage of the simple direct bleed system is the problem of possible contamination. Bleed air that has even momentarily experienced a temperature of 500° to 800°F. prior to entering an occupied area involves the possibility of introducing irritating contaminants that result from chemical decomposition of any foreign matter contained in the compressor air. The most likely sources of such contaminants are lubricants used in the compressor section of the engine or any accessory components over which the compressor air has passed. Prior to the advent of the high pressure and temperature ratio engines, manufacturers were not greatly concerned with

small amounts of oil leakage because irritating contamination did not appear. Apparently irritating products of decomposition do not result from such leakage unless the bleed temperature exceeds about 500°F. At present, however, engine manufacturers are being urged to take great pains to prevent the mixing of even minute amounts of oil or other fluids with compressor air. It is believed that the contamination problem can be reduced to a level that will be acceptable for commercial transport operation by such devices as (1) locating the internal bleed scoops on the hub side of the compressor blading and (2) the design of vented bearing seals that dispel leaking oil overboard.

In the meantime, two basic approaches are being investigated and evaluated as means of coping with contamination if and when it should occur. The first method is to develop a screening device for separating or otherwise destroying the contaminating elements. Devices in this category include filters, absorbers, and catalytic agents. The second method makes use of bleed-driven compressors or so-called pneumatic transformers. In either case the method can be applied for continuous operation during all pressurized periods, or it can be used as an emergency device to be available instantly whenever contamination is detected. In the latter arrangement there would be a considerable saving in weight and space, because the emergency device need only be large enough in a multiengined system to prevent depressurization for the period required to isolate the engine that is contributing the contamination. At best, however, these measures represent a penalty as compared to a simple bleed installation for which pure uncontaminated air could be guaranteed.

Air Conditioning—Separate Cabin Superchargers

Separate cabin superchargers driven either by engine shafts, hydraulic transmissions, electric motors, or bleed air turbines can conceivably be used instead of direct engine bleed air. Probably the most interesting of these superchargers is the bleed air-driven unit mentioned above, because it does not require a gear box and is therefore lighter and simpler than the others. Operation of a bleed turbocompressor usually requires no more bleed air than would be used in a direct bleed system if a variable nozzle turbine was used. Two or three units are required for adequate high altitude reliability.

The currently acknowledged advantage of the turbocompressor system over the straight bleed system is the greatly reduced possibility of contamination with the former. Because it can be a centrifugal compressor, can operate at reduced pressure ratios, and does not require a high-pressure lubrication system, this compressor is assumed to be a reliable "fresh air" source. However, there are several disadvantages to the turbocompressor system, and most of these come under the heading of "control complexity." The compressor characteristics are responsible for some of the complexity. Fig. 18 shows a schematic of a typical bleed-driven supercharger system. A compressor designed to deliver the required high altitude cabin flow must deliver a large excess of air at low altitude to avoid surge. Since it is uneconomical to refrigerate or heat this excess of air at low altitudes, it becomes necessary to spill the excess overboard with attendant loss in power. Alternatively, it is possible with two or three compressors to operate one at sea level and two or three at cruising altitude. The latter procedure requires a manual operation similar to blower shift in a supercharged piston engine. In either case, it is recommended by the equipment manufacturer that automatic spill valves be used to protect the compressors from possible misuse.

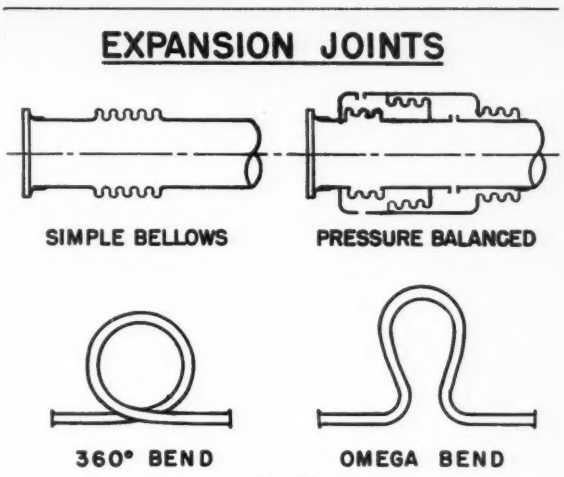

FIG. 16.

Cabin heating becomes a problem with the bleed-driven supercharger system. At high altitude the heat of compression may be adequate but some form of back pressure loading of the compressor, or perhaps a bleed air heat exchanger, is required to provide heat at intermediate and low altitudes.

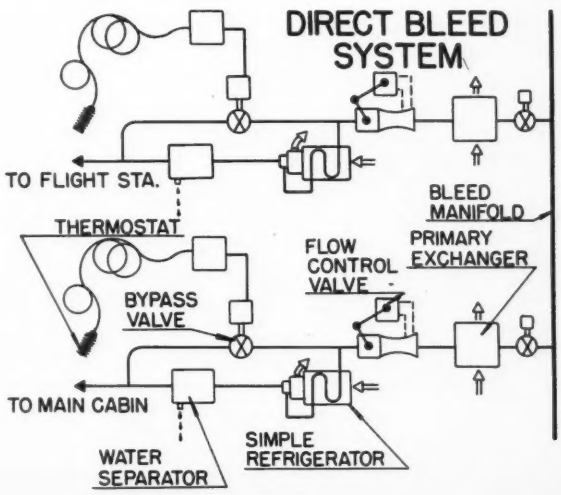

FIG. 17.

Cabin refrigeration by air-cycle system is still acceptable, but the more complicated "bootstrap" system is recommended to reduce compressor pressure ratio requirements and bleed air consumption at low altitudes.

The flow control system for the bleed-driven compressors would probably consist of downstream flow sensing devices that automatically position the variable area turbine nozzles. In a two-zone system with separate air-cycle refrigeration, a rather complex "brain box" is required to determine which zone needs the greater pressure for cooling, then make it available by adjusting the drive turbine nozzles, and then throttle the excess pressure to the other zone.

Air Conditioning—Ground Operation

The problem of providing ground refrigeration and ground heating in the turbine-powered airplane has received much attention recently. Air-cycle refrigeration and heating can, of course, be made available by means of bleed air from an auxiliary gas turbine, either air-borne or on a ground truck. The simple system refrigerator that best matches the engine bleed pressures requires higher pressures than are available from existing auxiliary gas turbines. The development of higher pressure auxiliary units is suggested, or, alternatively, the use of a two-position cooling turbine nozzle to accommodate both pressure sources more effectively.

The use of vapor-cycle refrigeration has been suggested to provide ground cooling at minimum power expenditure. This system has the attractive advantage of ground operation by electric power that is easily provided by a ground cart. However, it is difficult to justify the air-borne weight and bulk of the condenser and evaporator coils and the electric-driven compressor. It is noteworthy that the high speed characteristics of a bleed-powered turbine are quite compatible with the requirements of a small centrifugal vapor compressor, assuming that the high speed shaft seal problem can be satisfied. However, the adoption of the pneumatic drive as a weight-saving factor for the vapor system requires the use of a gas turbine ground cart, instead of the electric ground cart, in order to provide ground refrigeration.

Ice Protection

Turbine-powered aircraft are generally designed for high speed and high altitude. This means that while they are flying in icing conditions the design requirements for ice protection become severe, but the duration is brief since icing generally does not occur much above 20,000 ft. In piston engine aircraft, particularly nonmilitary types, it would be practical to reduce the

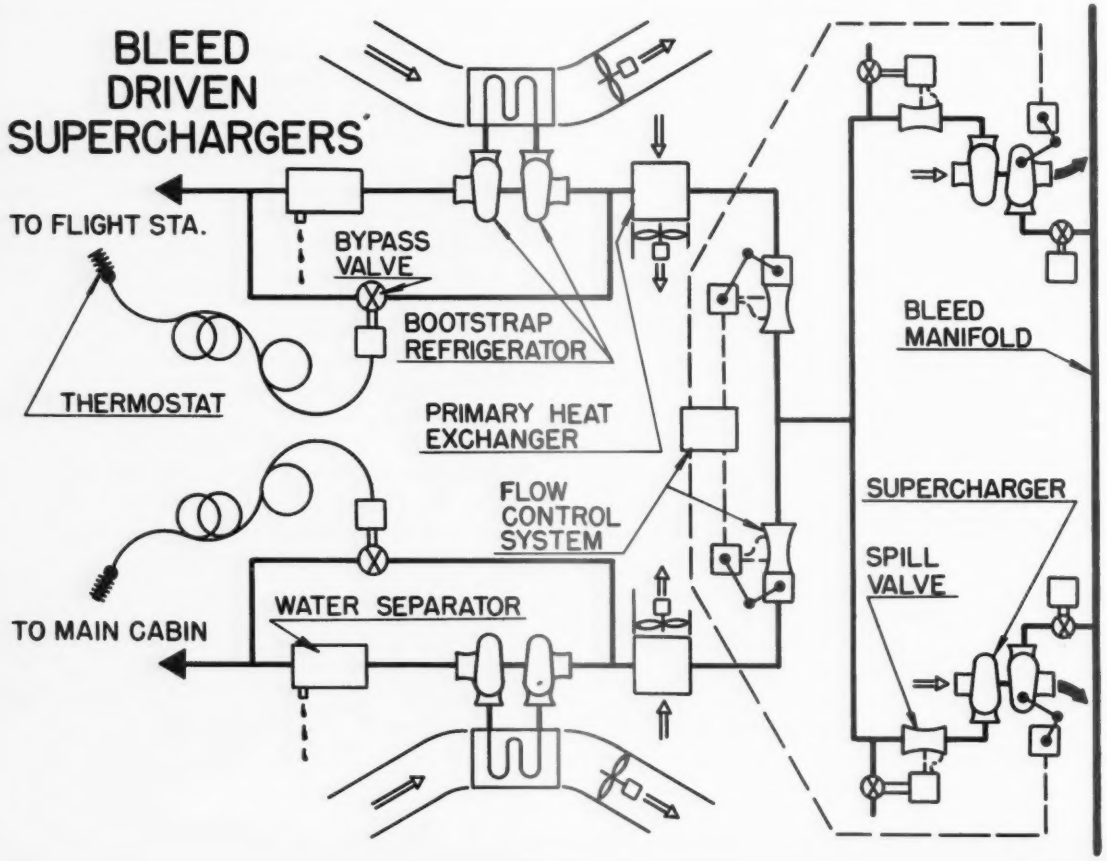

FIG. 18.

air speed in icing to alleviate the icing severity. In high speed turbojet aircraft, however, the amount of speed reduction possible is not significant.

The choice of systems for ice protection includes thermal anti-icing, thermal cyclic deicing, and inflatable boot deicing. It is not the purpose here to attempt to generalize on the best type of protection because that must be determined for each specific airplane design and mission. However, thermal anti-icing is now in wide use and is appropriate for many types of aircraft. The use of engine bleed air for thermal anti-icing and thermal cyclic deicing shows the advantage of minimum installed weight and maximum simplicity when compared to ram air systems using combustion heaters or electrothermal cyclic systems. The relatively high power loss and increased fuel consumption associated with the bleed air system can be justified for the average turbine-powered airplane that operates only briefly in the icing strata between sea level and 20,000 ft.

The heat requirements for thermal anti-icing are very large in the high subsonic speed range. The vast amount of heat required can best be delivered to the protected surfaces by means of engine bleed air, conserving its full temperature to minimize the bleed flow requirements. Duct heat losses can be minimized by the use of adequate thermal insulation. At the leading-edge double skin entrance, the high-temperature, high-pressure bleed air can be expanded in the nozzle of a jet pump and mixed with relatively cool exhaust air from the double skin, as shown in Fig. 19. The ejector serves a twofold purpose by reducing the temperature of the air in contact with the leading-edge skins and increasing the double skin airflow by recirculation. For example, a flow of 600°F. bleed air mixed with 200°F. exhaust air will almost triple the flow in the double skin passage if the mixture is controlled to 350°F. Thus, aluminum alloy skins can be used, and high heat transfer rates are obtained with a minimum expenditure of bleed air. The high airflows obtainable with this type of system produce a high overall system effectiveness and yet maintain a relatively low double skin temperature drop. The pumping effectiveness of the jet pump is sufficient to permit the use of high double skin velocities that cannot be obtained with a ram air system.

On some ice-collecting surfaces of the aircraft it may be desirable to use inflatable pneumatic deicing boots. The boots in use on today's airplanes depend on positive displacement pumps for inflation and deflation. In the turbine-powered airplane it is possible to use engine bleed pressure to inflate the boots and bleed-operated ejectors to deflate them. The high bleed pressures available are particularly useful for rapid and positive boot operation at high air speeds.

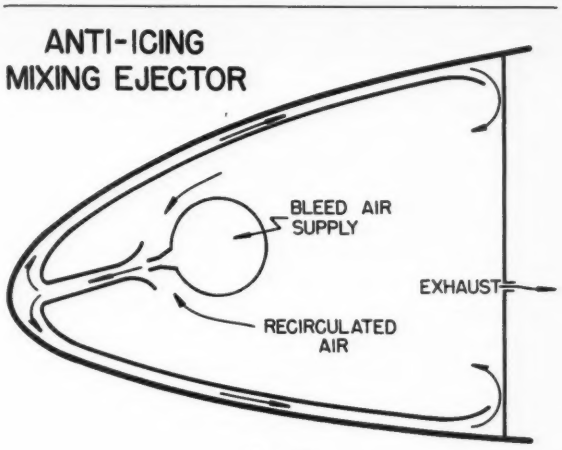

FIG. 19.

Engine Starting

The increase in turbine-engine output has been accompanied by a parallel increase in starting power requirements. Electric power has been largely abandoned in favor of other means for starting these larger engines. Foremost among these other means is pneumatic power supplied to an air turbine starter by either a ground or air-borne source. The pneumatic starter has proved to be a light and effective piece of equipment possessing a high power to weight ratio. However, the ground air compressor needed to energize the starter requires relatively high driving power and is expensive. This compressor is currently available in the form of a small gas turbine or an engine-driven industrial compressor of either centrifugal, rotary, or piston type. The gas turbine at its present stage of development is a light and portable unit but requires further development to improve its automatic controls, increase its life, and reduce its excessively high noise level. The engine-driven industrial compressor is built of more rugged components of proved reliability, but it is heavy and less portable. The vast weight advantage of the gas turbine over that of the industrial compressor permits the installation of the gas turbine in the airplane and thus provides a self-contained starting system. Even so, the weight penalty imposed by its installation with appropriate fire shielding is high (200 to 400 lbs. in a four-engined airplane).

Other self-contained starting systems have been proposed and are in use today. Among these are combustion starters using compressed air and engine fuel, monopropellant starters using fuels such as propyl nitrate, cartridge starters using gunpowder, and others. The compressed air supply for the combustion starters is stored in high-pressure (3,000 lbs. per sq.in.) shatterproof bottles and is throttled to about 150 lbs. per sq. in. before combustion and admission to the turbine. Considering the weight of the starters, storage bottles, and recharging compressor, the installation of a combustion-starting system on all engines of a four-engined airplane imposes a weight penalty of the same order of magnitude as for a gas turbine-pneumatic starting system. The use of a mixed starting system, incorporating combustion starters on two engines and pneumatic starters on the balance of the engines, saves considerable weight and provides self-sufficient starting

for the entire airplane through bleed air from the engines equipped with combustion starters. This system imposes the inconvenient necessity of starting particular engines first, which might become a first-class nuisance to the mechanic who wants to check out an engine equipped with a pneumatic starter.

It is apparent to those who have grappled with the engine-starting problem that further study and development work is required to perfect a system adaptable to multiengined aircraft. A proposal is therefore made which features a light pneumatic starter fitted with a simple two-position turbine nozzle control to permit quick starts from any of the three sources: (1) auxiliary gas turbine bleed air, (2) engine bleed air, or (3) bottled compressed air. The turbine nozzle in the small area position would be used for starts from engine bleed air or bottled air throttled to engine bleed pressures by a regulator. The large area position is intended for starts from auxiliary gas turbine air. Note that combustion would not be used with the bottled air in order to preserve the lightness and simplicity of the starters, and the consumption of bottled air would thus be more than double that required for the combustion starters in use today. The economic advantage and simplicity of portable compressed air bottles, as compared to the gas turbine or the engine-driven ground compressor, may change the starting requirements of many turbine-engine airplanes from "self-contained" to "external source." These bottles can be recharged by relatively inexpensive and low powered industrial compressors at a continuously operated ground station. Shatterproof bottles similar to, but larger than, those used for the combustion starting system are proposed. Handling the bottles for starting and for recharging would therefore be a relatively safe and simple operation.

Engine bleed plays a major role in this flexible starting system, because it is assumed that only one engine of a multiengined airplane would be started from the external source of air-borne system and the engine bleed ducts would be used to conduct the air to the first starter. The remaining engines would then be started by bleed air from the first engine.

Auxiliary Power Generation

Engine bleed air energy, as a major source of electric and hydraulic power generation through the use of air turbine motors, offers important advantages. The more obvious of these advantages are:

(1) Removal of heavy accessory drive loads from the engine itself and consequent reduction in engine shutdowns due to accessory or drive failure.

(2) Accessory speed control independent of engine r.p.m.

(3) In four-engined aircraft, accessory drive is relatively unaffected by reduction in engine power or by loss or deliberate shutdown of one or two engines.

(4) Removal of accessory from engine pad makes a cleaner, more accessible engine installation, reduces drag due to nacelle frontal area, and divorces accessory maintenance problem from that of the main engines.

In the case of electric power generation these advantages are particularly significant in view of the trend toward constant frequency alternating current to handle the large electrical loads of the multijet aircraft. The bleed air turbine lends itself well to the constant speed requirements of an alternator drive, and a large amount of electrical power can be generated by this means without affecting engine reliability or cluttering up the nacelle.

At this point it is necessary to look at the fuel economy of the pneumatic alternator drive. This machine must be designed to provide the essential electrical capacity over the wide band of aircraft operation from ground idle to climb and high altitude cruise. While the pneumatic drive eliminates the effects of varying engine r.p.m. there is instead the problem of varying bleed pressure and temperature and its effect on turbine efficiency. Generally, it is necessary to compromise cruise efficiency to provide adequate power during engine idle conditions. The degree of compromise, of course, depends on the range of engine operating conditions. As mentioned previously, the power obtained by bleed extraction costs more in engine fuel consumption than an equal amount of shaft power. This, together with the comparatively large continuous power requirements of the electrical generation system, makes cruise efficiency an important parameter in overall fuel economy. Thus, the design of the bleed turbine for alternator drive usually includes control by a variable area nozzle to minimize the efficiency losses over the wide range of operating pressures. Even with the variable nozzle, the cruise fuel consumption directly chargeable to the air turbine alternator drive can be as much as four times that of an equivalent engine pad drive. Of this estimated increase in fuel cost, about half is caused by a compromised cruise turbine efficiency of 50 per cent.

Thus, the problem of selecting an appropriate means of driving an alternator involves careful detail balancing of the fuel penalties due to bleed extraction against the advantages outlined above. The results of such studies will differ widely depending on the aircraft mission, engine operating schedule, and electrical power requirements.

The problem of hydraulic power generation is somewhat less difficult than that of constant frequency alternating current due to the less exacting speed control requirements. The pumps produce adequate pressure and flow over a wide range of engine r.p.m.'s. However, an air turbine hydraulic drive allows removal of the pumps from the engines with the attendant advantages previously listed. Here the choice left to the designer is either to locate centrally two or more pumps to serve all hydraulic power needs, or to disperse a number of pumps throughout the aircraft to serve local hydraulic systems. The previous discussion of engine fuel consumption penalties due to bleed-driven alternators applies equally well to bleed-driven

hydraulic pumps having continuous power requirements for flight control boost systems, etc. However, the drive turbine efficiency may be improved over that of the constant speed electric drive by scheduling r.p.m. according to available engine bleed pressure and thus maintaining a more favorable ratio of turbine speed to nozzle spouting velocity.

In the case of hydraulic utility systems serving the functions of landing gear retraction, flap extension, etc., the high efficiency requirements of a bleed turbine drive are minimized by the intermittent operating schedule of such systems. For this application consideration should be given to a simpler, throttle-controlled, pneumatic drive of moderate efficiency instead of the more complex variable-nozzle controlled turbine required for bleed air economy in continuous operation.

Stand-by or emergency power, hydraulic and/or electric, can be furnished by a small throttle-controlled air turbine in flight, and on the ground this same unit provides a high degree of aircraft self-sufficiency by energizing the hydraulic and electric systems of the airplane when operated by auxiliary gas turbine bleed air. A 400-amp. generator and a 7-gal. per min. hydraulic pump can be operated simultaneously at rated output for about 40 hp., requiring a bleed flow of about 1 lb. per sec. and a drive weight of about 30 lbs.

In some aircraft it will be necessary to provide a high pressure pneumatic system (3,000 lbs. per sq.in.) to serve, for example, as a means of engine starting and for utility systems requiring a rapid linear motion. The high pressure pumps used to recharge the storage bottles can appropriately be driven in flight by a bleed air turbine with the consequent reduction of electric or hydraulic load otherwise used for this purpose. The power requirements of such a compressor are generally moderate. For ground recharging of the storage bottles it is possible to use a direct transfer of high-pressure air from portable storage bottles, which are in turn recharged by a stationary industrial compressor. The in-flight recharging time can be appreciably reduced by supercharging with engine bleed air instead of ambient air at the compressor inlet.

Before leaving the subject of auxiliary power generation, a broad observation can be made in view of the penalties encountered in generating large amounts of electric and hydraulic power. It appears that if a bleed air drive is to be used, consideration should be given to the increased direct application of bleed air energy to functions normally served by electric and/or hydraulic motors. In this category are the actuators, large and small, used for operating landing gear, flaps, valves, tailpipe nozzles, etc. This calls for study and development of pneumatic linear actuators, perhaps incorporating two small turbine wheels for reversibility and driving the output shaft through appropriate reduction gearing. Use of such devices will reduce the losses incurred in the conversion of pneumatic power to electric or hydraulic power before transmission to the load. These pneumatic actuators should be particularly attractive in an airplane where an extensive bleed duct system already exists to serve cabin air conditioning, anti-icing, and auxiliary power generation.

The problem of ground checking devices powered by pneumatic actuators must also be considered. The use of either a pneumatic ground cart or air from high-pressure storage bottles is required for this purpose. The availability of one or both of these ground sources is likely if pneumatic or combustion engine starting and air-cycle cabin refrigeration are used in the airplane.

Boundary-Layer Control

A newcomer has recently been added to the multitude of functions demanding the services of compressed air from the main engines. This is boundary-layer control whose large pumping power requirements make the use of electric or hydraulic drive motors impractical. Fortunately, the bleed air demand for this function is momentary, occurring only at brief periods during take-off and landing. Bleed air jet pumps or high speed turbocompressors are proposed to perform the task of transporting the large quantities of air from the suction slots to the jet slots of the wing. The jet pump is simpler and weighs less than the turbocompressor, but its inherently low efficiency together with the high pumping power requirements may cause a bleed air demand in excess of engine manufacturer's limits. The need for operation of the boundary-layer control system during landing at low engine power requires the bleed air economy of a turbocompressor. Fortunately, this device need not be designed to accommodate high altitude operation, and thus high efficiency for its low altitude operation need not be compromised.

Reverse Thrust Actuation

Reverse thrust for turbojets, like boundary-layer control, is another new development that may require the momentary use of large quantities of engine bleed air for actuation. One particular scheme uses large jets of bleed air to assist in the deflection of the main jet. Other schemes require power on a smaller scale to operate jet deflectors but may require bleed air for deflector surface cooling.

Miscellaneous

There is a class of small accessory applications for which engine bleed air is a convenient means of applying pressure or motive power. These include auxiliary fuel tank pressurization for fuel transfer, tank vent air supply to prevent occurrence of negative tank pressures during a dive, hydraulic reservoir pressure for suppression of foaming, and the actuation of numerous valves. For most of these applications the bleed air must be cooled and throttled before it is used. Fortunately, the flow requirements are generally small and a reasonable length of supply tubing will cause sufficient heat loss. Simple, small pressure regulating valves for throttling are suitable to the working pressures of this class of equipment. In the case of fuel transfer at high rates it may be necessary to provide a small heat ex-

changer to reduce bleed air temperature to a safe level before allowing it to flow into the tank.

(V) Concluding Remarks

This paper has presented and discussed the major advantages and problems related to the use of turbine engine compressor bleed air in low-pressure pneumatic systems. Because of the wide variety of uses for this form of energy, it has only been possible to treat the subject rather broadly.

It is apparent, however, that certain general conclusions can be drawn as a guide to future development of systems and their components:

(1) Although bleed air has been shown to be a reliable, flexible, convenient, and simple source of heat and power, it should be utilized only after a careful evaluation of the resulting losses in engine power and fuel economy.

(2) In order to distribute bleed energy safely, the reliability of high-temperature and high-pressure duct systems must be developed to a degree comparable to any other primary component of the air frame, such as the fuel system, hydraulic system, or pressurized structure.

(3) Contamination of bleed air must eventually be eliminated by means of appropriate engine detail design.

(4) For at least the next few years, means for decontamination may be required for emergency use in bleed air systems.

(5) A quiet, compact, lightweight, and moderately priced source of compressed air of at least 50 lbs. per sq.in. gage must be developed to serve as a ground power and air-conditioning source for use prior to main engine operation. A small but low-pressure-drop disconnect means must also be developed for this application.

(6) When complete self-sufficiency of the airplane is necessary, some form of air-borne auxiliary gas turbine appears to be the best answer. Such gas turbines should incorporate a maximum of flexibility so that they may be used as sources of compressed air as well as shaft power. These gas turbines should be so designed that, if necessary, they can be operated on main engine bleed air as "bleed-and-burn" turbine motors or air compressors.

(7) When the degree of self-sufficiency is limited to self-contained engine starting, consideration should be given to a more flexible form of pneumatic starter capable of operation from any of the following three sources of compressed air: (a) auxiliary gas turbine, (b) main engine bleed air, or (c) high-pressure bottled air. Such a starter might require a variable or two-position nozzle. An air-borne means of charging the storage bottles might be a multistage air compressor capable of delivering 1 to 2 lbs. per min. at 3,000 lbs. per sq.in. and powered by an air turbine.

(8) Studies should be conducted to determine the relative suitability of turbine-driven linear actuators for certain high-load functions now being served by electric or hydraulic power.

The state of the art of low-pressure pneumatic system design is relatively young. As in all other phases of aircraft development, the validity of an analysis of anticipated new problems can be determined only after sufficient airplane experience. Depending on the degree of conservatism, this paper may have overemphasized some problems and overlooked others that are not now anticipated. At the present time the aircraft industry is developing low-pressure pneumatic systems for a number of new turbine-powered airplanes, and it is expected that much new information with regard to these problems will be available in the near future.

IAS Twenty-Third Annual Meeting

Hotel Astor, New York City, January 24–28, 1955

The Meetings Committee plans to schedule sessions on Aerodynamics, Aeroelasticity, Design, Electronics, Flight Propulsion, Instruments, Rotating Wing Aircraft, Safety in Flight, Structures, etc.

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Is the Present Aircraft Structural Factor of Safety Realistic?

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Introduction

The philosophy in airplane design has changed considerably in many respects during the past years. Performance is continually improving. Flight characteristics affected by this improvement sometimes necessitate changes in design philosophy. For example, low landing speeds at one time were considered essential to the safety of aircraft. With the demand for better high-speed performance, aircraft runways have been increased in length, and it has been possible to produce aircraft that are considered to have adequate safety despite much higher landing and take-off speeds. There are many similar examples of changes in criteria and design philosophy.

One of the requirements which has been with us for many years without a change is the value given to the aircraft structural factor of safety. Is this presently required factor of safety realistic?

This paper presents a discussion of various aircraft design considerations in relation to this factor of safety with the aim of stimulating thought and further discussion on this question.

Discussion

Definition of Ultimate Factor of Safety

The ultimate aircraft structural factor of safety is defined as the ratio of design ultimate load to design limit (or actual applied) load on the structure and is usually equal to 1.5 for military and commercial aircraft unless otherwise specified. It may be interesting to note why the value of 1.5 was originally selected. One of the earlier interpretations of factor of safety in aircraft was given by T. P. Wright on October 4, 1928, at the First National Aeronautical Safety Conference under the joint auspices of the Daniel Guggenheim Fund for the Promotion of Aeronautics and the National Safety Council, in an address entitled, "Structural Analysis and Design in Relation to Commercial Aviation Safety." The following is quoted from this paper:

"Ultimate stresses in the material divided by the working stresses in design gives the factor of safety. For bridges, buildings, and the like, the factor of safety is about four to five. In airplane design, it rarely exceeds two and is frequently used at one and one-half. This factor must take care of possible defects in material and workmanship; of design inaccuracies; of errors in assumptions; and of depreciation. The justification for the use of such a low factor of safety in a structure such as the airplane, where freedom from danger is so important, is the extreme care used in selecting load factors; the refinements used in preparing stress analyses; and the care used in selecting, inspecting and testing the materials."

An excellent historical summary of the subject of Required Factors of Safety for Design of Civil Aircraft was prepared for the writer by George D. Bogert and Armer M. Alcorn, of the Los Angeles Regional Office of the Civil Aeronautics Administration, and is given in Appendix A. This summary reveals that in the 1929 issue of Aeronautics Bulletin No. 7-A, *Airworthiness Requirements for Air Commerce Regulations*, the load factors specified for given design conditions were ultimate load factors and included any required factors of safety. However, some special factors, referred to as multiplying factors, were specified for details of the primary structure such as fittings. The values for the ultimate load factors were dependent on gross weight and power loading. In the 1934 revision to Bulletin 7-A, this design ultimate load factor was modified to an "expected" or "actual" load factor plus a factor of safety which was specified as 1.5 to represent a minimum value. This "actual" load factor was called the applied load factor, and the following definition was given to factor of safety:

Factor of Safety—The factor of safety is an arbitrary factor by which the applied loads or load factors are multiplied for the purpose of ensuring sufficient strength to permit the applied loads to be exceeded by a definite amount before complete failure of the structure occurs. In general, the factor of safety also provides sufficient strength to prevent permanent set under the applied loads. The total factor of safety may include special factors to ensure extra strength or rigidity in certain cases.

In the first edition of Civil Air Regulations, Part 04, in 1938, the term "limit" was introduced to specify the actual or expected load factor. However, the basic required factor of safety of 1.5 was retained.

The basic design requirement philosophy of the 1938 edition of CAR 04, insofar as factors of safety are concerned, has been retained to date for civil airworthiness design requirements. The history of the development of the factor of safety used in the design of military aircraft is very similar, as may be noted in Appendix B on the same subject for USAF aircraft. The same value of

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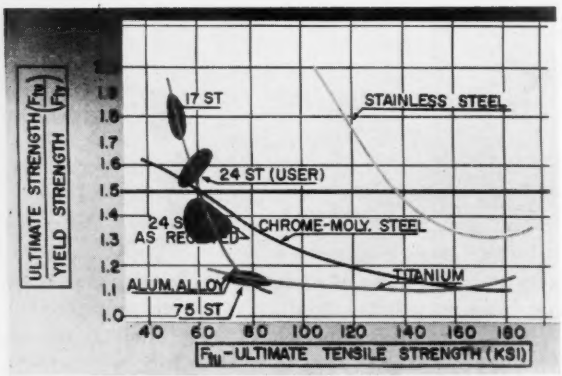

FIG. 1. Variation of F_{tu}/F_{ty} with tensile strength for aircraft structural materials (room temperature).

1.5 is specified for ultimate factor of safety by both the Air Force and the Bureau of Aeronautics. However, the Bureau of Aeronautics specifies a yield factor of 1.15 above the limit loadings.

On the basis of the foregoing, it may be stated that the most important reasons for establishing an ultimate factor of safety of 1.5 over the limit loads are allowance for no permanent set or yielding at limit load and allowances for defects in material and workmanship, for design uncertainties and inaccuracies, for stiffness, and for exceeding specified maneuvers.

I would like to discuss in detail each one of these reasons and point out some of the changes which have come about, or may come about in the future, to influence our thinking with regard to retention of the present required ultimate factor of safety of 1.5.

Allowance for No Permanent Set or Yielding at Limit Load

As discussed previously, the ultimate factor of safety of 1.5 was established for commercial use in 1934, and the general thinking in the years that followed was that the value of 1.5 was selected so that the structural materials used in aircraft design would not yield, and the structure would not have permanent set at limit or applied loads. Let us look at the physical properties of the structural materials used up to that date and those used since.

Fig. 1 shows the variation in the ratio of the ultimate to yield strength with the ultimate strength of aircraft structural materials at room temperature. It may be noted that, with the exception of the lower hardness stainless steels, 17ST and 24ST (user) aluminum alloys, and mild steel, all other materials have a ratio of ultimate to yield strength less than 1.5 at room temperature. The value is considerably lower for 75ST aluminum alloy, which is extensively used as a structural material for maximum strength requirements.

Fig. 2 shows the variation in the ratio of ultimate to yield strength with temperature for 24ST (user), 24ST (as received), 75ST, and titanium, Here, again, 75ST aluminum alloy at elevated temperatures has an ultimate to yield strength ratio considerably less than 1.5.

Fig. 3 shows a trend in the use of structural materials plotted against the ultimate to yield strength ratio. It may be interesting to note that the ultimate factor of safety of 1.5 was established in 1934 for commercial use at about the same time that 24ST aluminum alloy, having approximately the same value for the ultimate to yield strength ratio, came into general use in aircraft design. Even with the more recent use of the higher strength aluminum alloys and high heat treated steels that have a low ratio of ultimate to yield strength, the ultimate factor of safety of 1.5 is still retained. Because of the higher yield strength, permanent set or yielding (especially in tension) of aircraft components using these higher strength materials will no doubt occur considerably above the limit or applied loadings and closer to the ultimate loadings on the airplane. This fact is also true for compression surfaces of most modern high-speed, thin-wing aircraft that use thick skins in their construction. In many such cases there is very little evidence of permanent set or yielding before complete collapse at ultimate loading. Therefore, with currently available structural materials, if the design is to be predicated on the criteria of permanent set or yielding just above limit load (1.15 × limit load for BuAer), the ultimate factor of safety selected must be based on some criteria other than the ratio of ultimate to yield strength of the structure.

Allowance for Defects in Material and Workmanship

Some people have considered the factor of safety of 1.5 to allow for defects in material and workmanship. All modern aircraft companies have well-established quality control departments with trained inspection personnel and facilities to keep the quality of workmanship up to the high standards required today by the military services and the air lines. Materials and structural components can be and are rigidly inspected by X-ray, ultrasonic, Dy-Chek, magnetic, and other means. Such facilities were not generally available in 1934. Some allowances, no doubt, will have to be made even today because of the increased complexity in fabrication; increased rate of production; new materials and processes; and increased number of less ex-

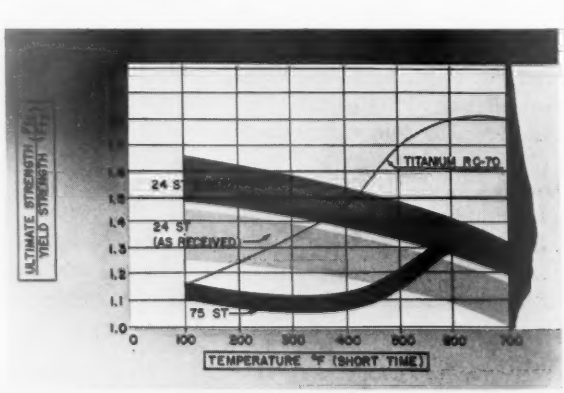

FIG. 2. Variation of F_{tu}/F_{ty} with temperature.

perienced workers. However, in the writer's opinion, the balance has undoubtedly shifted to the plus side as improved quality both in fabrication and in control and inspection techniques more than compensate for more severe technological complexity.

Allowance for Design Uncertainties and Inaccuracies

It has been stated by many that the factor of safety provides for design uncertainties and inaccuracies. It is true that such conditions did exist years ago, but recent technological advancement in aircraft design has been outstanding. Some of the problems we were then faced with, but were not yet prepared to handle, might be enumerated.

(a) Aeroelastic effects.
(b) Fatigue.
(c) Flutter.
(d) Dynamic effects.
(e) Structural complexity.
(f) Loading spectra and load distributions.

How are we handling these problems today? Let us see how each is considered in present-day design.

(*a*) *Aeroelastic Effects*

Aeroelastic effects have existed on most airplanes in varying degrees. When wings and tail surfaces were thick, airplane speeds were low, and structural materials with low physical properties were used, the aeroelastic effects were relatively small and could be safely neglected. Today's aircraft, however, must consider aeroelastic effects for proper performance and strength. The elastic characteristics of the airplane are investigated thoroughly for wing divergence, aileron reversal, stability and performance, and load distribution changes. Some companies are now performing wind-tunnel tests to obtain force and pressure distribution data on models that closely represent the elastic characteristics of the airplane. I firmly believe that more and more of the companies should, and will, design and build elastically similar models in order to obtain deflection data that can be utilized in stress analyses, dynamic and flutter analyses, and aerodynamic load determinations. This, I believe, will be just as much a requirement in the future as a wind-tunnel model has been in the past.

(*b*) *Fatigue*

Fatigue has been of concern for some years in the design of commercial aircraft and only recently in military aircraft. In the past, few explicit fatigue studies were carried out on aircraft structural components or details during the design stages as it was believed that sound detail design was sufficient. It was only after failures occurred in service that fatigue studies were made and tests were carried out, mostly in the form of slow repeated-load tests rather than at the higher frequency tests possible today. Early failures usually occurred in

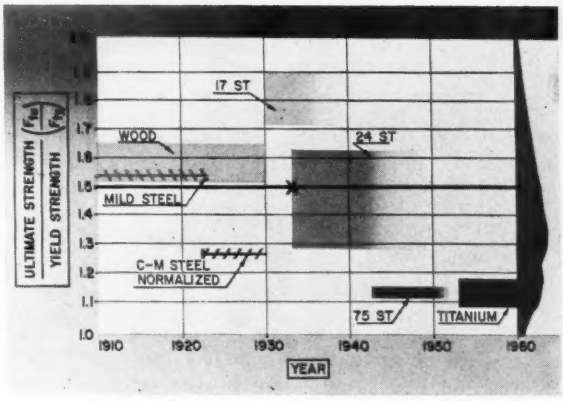

Fig. 3. Trend in use of structural materials.

landing gears, and repeated load tests were resorted to in order to produce an adequately serviceable article. One of the first cases of fatigue failure of a wing on a commercial airplane resulting in a major catastrophe occurred in 1948 when a two-engined commercial air liner failed during a severe storm. Since then there have been cases of fatigue failures in military aircraft as well as in other commercial aircraft. Consequently, all aircraft companies are fatigue-conscious in the design of all types of aircraft. Fatigue analyses on the complete aircraft using available loading spectra in landing, gusts, and maneuvers are being carried out by many companies during the design stages to provide adequate fatigue strength. Much more fatigue testing of structural details, structural components, and even complete airplanes is being done at the present time than ever before. Many of the companies have installed equipment that can perform fatigue tests on heavily loaded components at a high loading rate. There is great need for more realistic load spectra of various classifications of airplanes in maneuvers and in turbulent air as a function of types and structural characteristics. Few data are available on load spectra for tail surfaces of aircraft. These surfaces are subjected to loads due to maneuvering, turbulent air buffeting, jet exhaust vibrations, etc. More realistic load data would be useful in predicting fatigue life, both experimentally and theoretically. Until such complete data are available, fatigue-warning devices perhaps should be put on some service airplanes. Devices that have been proposed include counting accelerometers and strain gages, crack detection wires, and fatigue-damage monitors or coupons. Data accumulated by such means will have to be utilized in conjunction with results from full-scale fatigue tests.

Many people have expressed the opinion that it may not be possible to utilize the higher allowable tensile stresses of the new materials being developed because of fatigue considerations. Every attempt should be made to utilize this increased allowable tensile stress. Making every effort to avoid high concentrations by the use of machined skins, forged surfaces, integrally stiffened skins, metal-to-metal bonding, and other means, and by substantiating tests, it may be possible to utilize the

higher allowable stresses and still satisfy the fatigue requirements. There has been so much interest in the problem of fatigue that the Aircraft Industries Association has formed an Industry Panel on Fatigue in order to coordinate the efforts of the various companies and improve the knowledge of this subject. This panel will have for its scope design and analysis, environmental conditions, operations, and materials.

The objectives of the panel are to:

(1) Review and correlate current data, analytical methods, and theories on fatigue.

(2) Develop recommendations based on such current information, including industry-recommended practices for design, for analytical methods of evaluation, and for repeated-load tests.

(3) Establish methods for effective exchange of information among companies as deemed desirable.

(4) Develop recommended research and testing programs as necessary to provide missing basic data.

(5) Recommend further required action by industry to achieve its goal.

I am sure that when these objectives are accomplished, the aircraft designer will have a better knowledge of the fatigue problem. Therefore, if fatigue is adequately considered in future designs, it might be realistic to consider a reduction in the present required ultimate factor of safety if some part of this factor had been used in the past to prevent fatigue failures. This thought was also expressed by F. R. Shanley in his Project RAND Report RM-1127, *Fatigue Analysis of Aircraft Structures*.

(*c*) *Flutter*

Flutter has been of considerable importance in the past and will become even more important as the speed of aircraft is increased and the structure becomes more flexible. Most large aircraft companies today have flutter engineers who are continually investigating, not only analytically, but also experimentally, the flutter conditions of the airplane that is being designed. Many companies make flutter investigations by analytical methods, using the modern analog and digital computers to include many degrees of freedom to get their answers. In addition, experimental tests are carried on flutter models in the wind tunnel to determine the flutter characteristics. These wind-tunnel flutter model tests can be carried out in a relatively economical manner and fixes can be studied, such as moving masses into different locations or mass balancing. By carrying out wind-tunnel tests on a dynamically similar model of the airplane being designed, it is possible to determine the flutter characteristics and make necessary changes while the design is progressing, well in advance of the manufacture of the actual article. A recent technique, which has been utilized successfully in determining flutter characteristics, has been the use of the high-speed sled at Edwards Air Force Base. A full-scale structure, such as the tail of an airplane, can be mounted on this sled and flutter tests performed at transonic and low supersonic speeds. These tests yield results in a short time and changes can be made readily to improve flutter characteristics if necessary. It is anticipated that more of such testing, especially in the high-speed ranges, will be carried out in the future to supplement the small-scale wind-tunnel model tests. Final proof of flutter freedom is to fly the airplane to the limiting speeds in a carefully planned flutter flight-test program. It is true that as higher speeds are approached, less is known about the flutter characteristics of the airplane. However, the three-step program just outlined—i.e., the analysis, the experimental model program, and the full-scale flight flutter program—should ensure that the airplane is safe from flutter.

(*d*) *Dynamic Effects*

Many years ago, very little was done about the dynamic effects on the structure of the aircraft. However, when failures developed in landing gears and large masses dropped off wings during hard landings, the engineers started to make dynamic investigations of their aircraft for the landing conditions. In many cases, these dynamic investigations in landings have resulted in loading conditions on the aircraft that are more severe than static loading conditions. Designs proceed on these analytical investigations and are finally verified by full-scale landing tests at the specified rates of descent for the particular airplane. Most modern aircraft are instrumented for landing tests in order to verify the analyses made for the critical landing conditions.

In recent years, considerable interest has been shown by the various procuring agencies in the dynamic effects of the aircraft in turbulent air. Many companies make dynamic analyses of their aircraft for turbulent air response as well as abrupt control surface response. As in the landing conditions, attempts have been made recently to verify the dynamic analytical investigations by full-scale flight tests in turbulent air. NACA has done considerable work along this line, and some of the aircraft companies are carrying out similar studies on their own aircraft. Recently, the Northrop Company completed such a flight-test program on a fighter that was completely instrumented for flight loads. This airplane was instrumented so that bending moments along the span of the wing would be determined. The airplane was flown throughout turbulent air at various speeds and in various weight conditions. Accelerometers were located at the nodal points on the wing in order to estimate the gust velocities encountered. The results of these flights showed very good correlation with the analytical dynamic investigations. The close agreement can be attributed in part to the accurate information that was available on the stiffness of the wing structure for use in the analytical calculations. The stiffness information was available from full-scale tests on a static test airplane. Similar information could have been obtained by stiffness tests of an

elastically similar model, as mentioned previously for use in flutter and aeroelastic studies.

(e) *Structural Complexity*

It has been stated by some that the present factor of safety makes allowances for structural complexities. It is no doubt true that with the present-day demand for higher performance, wings are becoming thinner and the airplane structures more complex. Weight is of paramount importance, and the designer is doing his utmost to be able to produce a minimum weight airplane. The stress analyst is investigating a multitude of design conditions in order to be assured that the critical loadings on the various parts of the airplane have been determined. Jerome F. McBrearty of Lockheed Aircraft, in a recent paper, "Structures for High Speed Aircraft," pointed out that powerful methods and devices are available in most aircraft companies to attack the aircraft structural problems with a minimum chance of error in the analytical work. Here, again, experimental testing of structurally similar models should be considered if the structure is so complex that conventional means of analysis cannot be used. With the present trend toward thinner wings and such configurations as delta wings, it is necessary for the structural engineer to obtain a better knowledge of the behavior of the structure under various loadings. Fig. 4 shows the elastic response under application of point torque loads on a multispar wing with wide rib spacing. The torsional deformation of this wing is somewhat different from the deformation structural engineers have visualized in the past for more conventional structures. This variance in response naturally affects aeroelastic loads along the span of the wing, as well as the stress distribution in the wing.

As in the flutter investigations, the structural engineer has a three-step program to verify the structural integrity of the airplane. First phase is to make the analytical studies. This phase could be supplemented by tests on an elastically similar model in order to determine the stiffness characteristics. Also supplementing this first phase should be a series of fatigue and static tests on small components of the airplane. The second phase is to perform static tests on the complete airplane for the critical loading conditions. The third phase then is to perform a complete flight loads program on the airplane to verify the analytical loads used in design and in static tests. Some companies use this last phase not only to verify the analytical investigations but also to be able to increase the gross weight of the airplane if it is at all possible. These flight programs are rather extensive and, incidentally, very expensive. If an airplane program is established which includes a flight loads program, it should be possible to design the airplane for minimum weight with an optimistic viewpoint, since the loading data will be available from flight tests and corrective action can be taken if necessary before any aircraft are released for unrestricted operation.

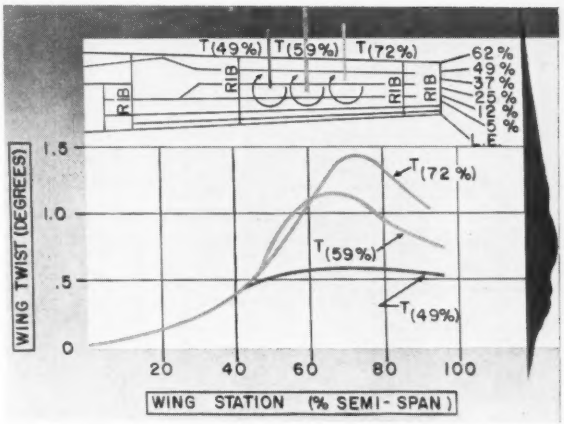

FIG. 4. Elastic response in torsion of a multispar wing.

(f) *Loading Spectra and Loading Distributions*

It is true that there has been a lack of adequate loading spectra for various airplanes in maneuvers, gusts, and landings. Every effort is being made to obtain statistical data that can be used not only for fatigue studies but also to obtain realistic and compatible design loads for use in providing adequate static strength. NACA has been obtaining gust data on various types of aircraft for many years. This information has been available and is used in the design of aircraft. When failures in aircraft occurred because of hard landings, programs were set up by both the Air Force and the Bureau of Aeronautics to determine realistic sinking-speed requirements for carrier-based and land-based aircraft. More recently, maneuver data have been and are being accumulated on military aircraft in training and in operation. Considerable maneuver data were made available from the recent operations in the Korean fighting. More military and commercial aircraft are being instrumented with VGH recorders in order that more realistic loading spectra can be obtained for different types of aircraft. In addition, programs are being planned to obtain statistical pitching, rolling, and yawing data for the purpose of establishing more realistic criteria for such maneuvers. The aerodynamicist is becoming more conscious of the fact that wind-tunnel model tests should provide complete load data as well as stability and performance data. Both high speed and low speed elastic wind-tunnel models should be tested to obtain pressure distribution data as well as force data for the structural engineer. The flight loads programs mentioned previously determine loadings accurately by either pressure measurements or strain gage instrumentation. As more accurate and realistic statistical information and test data become available in greater quantity, the aircraft designer is enabled to design airplanes more efficiently.

Allowances for Stiffness and for Exceeding Specified Maneuvers

The various points I have just discussed indicate that since the ultimate factor of safety of 1.5 was first

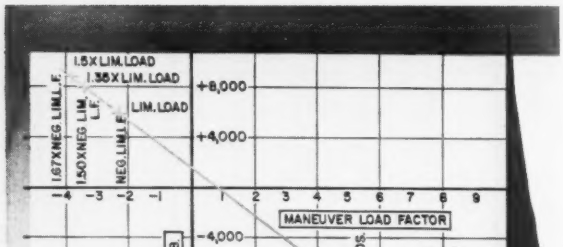

FIG. 5. Horizontal tail load vs. load factor.

established, there has been considerable technological advancement in knowledge of the behavior of the airplane in the air and on the ground, as well as of the internal behavior of the structure. Perhaps we should now review this value of 1.5 because of this increased knowledge. Many have stated to me that it is not possible to reduce this value because of the following two major factors:

(a) Many aircraft will be designed for stiffness rather than strength.

(b) Many aircraft exceed limit load factors in emergencies or inadvertently, and the factor of safety of 1.5 allows strength for such cases.

These two points are certainly strong reasons for an ultimate factor of safety. The question is whether creative thinking and good engineering judgment can be applied in the design of new aircraft to ensure that these points do not become of major importance when considering a reduction in the ultimate factor of safety. How can this be accomplished? Some people have already provided some of the answers.

(*a*) *Stiffness Considerations*

Few airplanes of the past have been designed for stiffness rather than strength. In cases where this has occurred, the stiffness allowances have been made after the configuration has been established on the basis of strength. These stiffness allowances have been made either for aeroelastic reasons or for flutter considerations. Even so, in many such cases, configuration changes have been made wherein masses of equipment or engines have been shifted into other locations so that the stiffness allowances have been either reduced or eliminated completely. It is my contention that good engineering judgment can be applied in the preliminary design of an airplane so that the airplane is designed for strength rather than stiffness. This judgment will have to be supplemented with adequate testing in order to attain this goal. Aeroelastic effects can be minimized by other means than the brute force of increasing torsional stiffness. For example, wing divergence speed can be increased if the torsional axis of the wing is ahead of the aerodynamic center. Reduction of wing aspect ratio and increase in taper are highly beneficial for all the common aeroelastic problems. The effect of sweepback of the wing is also beneficial for divergence. All movable wing tips for aileron control eliminate adverse twisting moments and can eliminate the problem of aileron reversal. Aerodynamic spoilers for lateral control can also be designed to reduce the aileron reversal problem. Judicious location of masses can reduce the flutter possibilities. These aeroelastic problems are serious for high-speed aircraft, particularly if the aspect ratio is fairly high. It is for this reason that consideration should be given to many seemingly unattractive solutions if airplanes are to be designed to minimum weights.

(*b*) *Exceeding Specified Maneuvers*

The problem of exceeding limit load factor either inadvertently or because of an emergency is a realistic and serious one. As mentioned previously, statistical information on load factors encountered during operational conditions is being assembled for both military and commercial aircraft. Evidence is available that design limit load factors are being exceeded frequently, especially during training and fighting operations rather than during routine operational conditions. It is less probable for a transport or bomber to exceed design load factor than a fighter-type aircraft under pilot-controllable conditions. If statistical data indicate a high probability of exceeding design load factor, then the specified design limit load factor is not realistic and should be raised rather than counting on a factor of safety of 1.5 allowing for these probabilities.

I am certain that catastrophic failures of the past can be attributed more to inadvertent conditions than to pilot-controlled conditions. It should be the designer's aim to develop airplane control characteristics that will provide adequate control within the mission of the airplane but, at the same time, prevent the pilot from exceeding limit loading conditions by more than a small amount. If this cannot be done by aerodynamic means, then the designer should resort to servomechanisms. One method to avoid exceeding the design load factor is to design and install a satisfactory *g*-limiter. Many people have objected to such an installation and parallel it to an automobile governor, which no one wants. Pilots want to be able to get out of emergencies and will exceed design limitations whenever it is necessary. However, this could be made a matter of deliberate rather than reflex action. Also, perhaps there are certain types of airplanes that operate under controlled conditions all the time and need no provisions for exceeding design load factor. Bombers, cargo planes, and transport planes might be put in this class and, possibly, could have installed *g*-limiters for safety. Bomber interceptors might be put in this class at some future date when operational conditions are handled by automatic controls rather than by the pilot. Missiles definitely operate by automatic controls and, therefore, cannot exceed the design conditions once the

test phases have been passed and they are operational. The following statement was made by Lt. Gen. James H. Doolittle in the January, 1954, issue of AIA Publication, *Planes*, in which he predicts the ten most likely advances in future years:

"... substantially automatic operation of many types aircraft. With certain military planes already operational, the pilot serves primarily as monitor—with most of the actual flying done by electronically directed and operated automatic controls. In the next half century, we shall see extensive refinement and development of electronic and automatic flight equipment, with control (from take-off to touchdown) in most military aircraft, entirely automatic. This leads to pilotless, controlled, supersonic and hypersonic (ballastic) air weapons. In the air transport field, this new equipment will contribute to even further advances in safety and schedule reliability."

Because of the trend to automatic operations, the design load factors for various types of aircraft using such controls shall be those selected to be satisfactory for operation, and there should be no need to design above the limit loading conditions. Design, in such cases, should be predicated on no permanent set or deformation at the limit loading conditions.

Ultimate Factor of Safety and Ultimate Load Factor

Many people have thought that an ultimate factor of safety of 1.5 indicates that the airplane strength is good for an ultimate load factor of 50 per cent above the limit load factor. This is an erroneous idea and, if considered, can produce catastrophic results in some cases.

Present procedure (BuAer excepted) is to design a part for no perceptible permanent set or yield at limit loading and limit load factor and failure at the ultimate loading, which in most cases is the limit loading times the 1.5 factor of safety. Due to aerodynamic characteristics influencing the air loads and air load distributions, some parts of the airplane structure can have ultimate load factors at the ultimate loadings (1.5 times limit loads) greater or less than 1.5 times the limit load factor. A good example of this is given in Fig. 5, which shows the variation in horizontal tail load with factor of safety for a particular airplane. A factor of safety of 1.5 on the limit tail load will permit the airplane to exceed the positive limit load factor by 40 per cent and the negative limit load factor by 67 per cent. However, if it was desired to have an ultimate load factor 50 per cent greater than the limit load factor, then the corresponding tail loads would be 61 per cent and 35 per cent above the limit tail loads.

Fig. 6 shows the variation in the torsional moment about the elastic axis at the root section of the horizontal tail with factor of safety. Here, again, for a 50 per cent increase in limit loading, the ultimate torsional loads would provide only a 37 per cent increase in positive load factor and as much as 80 per cent increase in negative load factor. For an ultimate load factor 50 per cent greater than the limit load factor, the corresponding loads would be 66 per cent and 31 per cent above the limit loads. The data are based on the assumption that structural behavior and aeroelastic effects are the same above limit loadings as below. This, we all know, is not strictly true, for structural behavior can be nonlinear as yield or initial buckling of the structure is exceeded, and, consequently, the aeroelastic effects become nonlinear and produce nonlinear loadings. Therefore, the values shown in Figs. 5 and 6 for the ratio of ultimate load factor to limit load factor can be quite different if possible nonlinearity above limit loading is taken into consideration.

There are many structural parts of an airplane wherein such loading conditions exist. A pilot is guided by the accelerometer on his airplane and limits his maneuvers below the specified limit load factors. Because of emergency conditions, it may be necessary to exceed the limit load factors by a small amount. This small amount may produce catastrophic loadings in some cases and conservative loadings in others; therefore, the present required factor of safety cannot be considered as being realistic. It may be necessary to consider a higher factor than 1.5 for the case where 1.5 times the limit loads permits only a small margin between ultimate load factor and limit load factor. However, it should be possible to consider a lower factor than 1.5 for the case where 1.5 times the limit load permits a large margin between ultimate load factor and limit load factor. Another example of this point may be given in the gust loadings on an airplane. Figs. 7 and 8 show the load factors developed during a 50K gust at various speeds for a low wing loading and a high wing loading airplane, respectively. If it is assumed that the ultimate gust velocity encountered is 50 per cent above the limit design gust velocity, then the following ratios of ultimate load factor to limit load factor would result at the critical design speeds:

Wing Loading	Ultimate Load Factor	
	Limit Load Factor	
W/S (lbs. per ft.^{2})	Positive	Negative
48	1.42	1.62
130	1.20	...

Here, again, the nonlinearity of loadings and structural behavior above limit load should be considered. However, it should be realistic and possible to reduce the ultimate loadings for positive gusts below 1.5 times the limit loadings because of the greatly reduced probabilities of encountering the higher gust velocities.

Advantages in Reducing the Factor of Safety

In the previous discussion, I have tried to point out some of the technological advancements in airplane design since the ultimate factor of safety of 1.5 was first established in 1934. Mr. McBrearty, in the paper mentioned earlier, also has pointed out the great advancement in structural knowledge which is contributing to the refinement of airplane design. With this increased knowledge and refinement, it should be possible in the

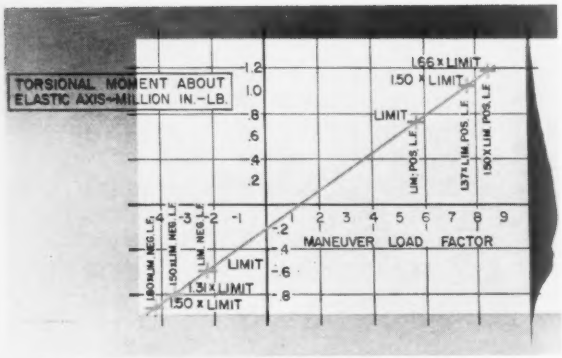

FIG. 6. Horizontal tail torsional moment vs. load factor.

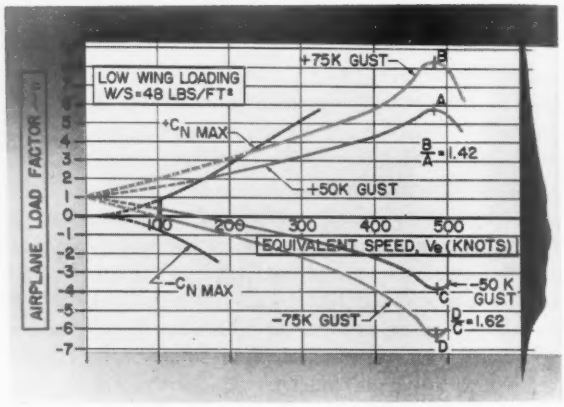

FIG. 7. Gust *V-n* diagram (low *W/S*).

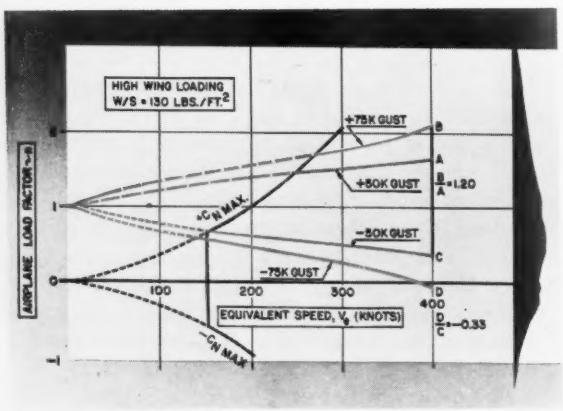

FIG. 8. Gust *V-n* diagram (high *W/S*).

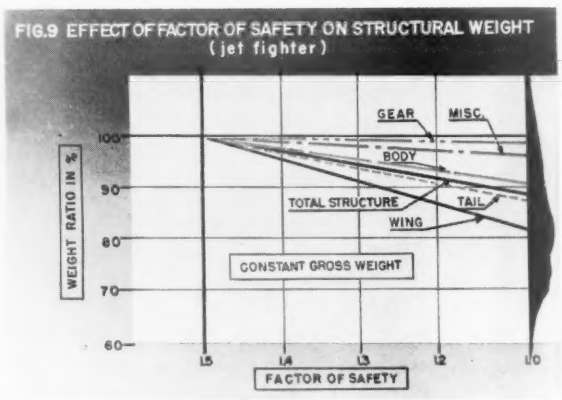

FIG. 9.

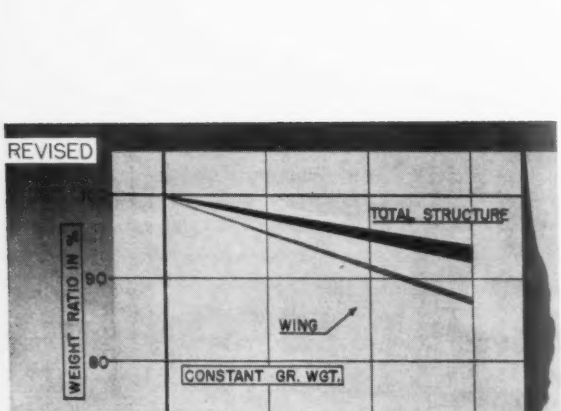

FIG. 10. Effect of factor of safety on structural weight (jet fighter, jet bomber, piston cargo).

FIG. 11. Effect of factor of safety on range.

future to design airplanes with increased performance and at minimum cost. Let us take a look at the advantages we can gain if the factor of safety could be reduced below 1.5.

Fig. 9 illustrates the weight variation with factor of safety of the different structural components of jet fighter-type aircraft. The data are based on constant gross weight and constant performance. They indicate that the greatest percentage reduction in weight is for the wing. Also, since the wing is usually the heaviest structural component, its weight reduction in pounds is much greater with factor of safety decrease than for any other structural component.

Fig. 10 illustrates the weight variation with factor of safety of the wing and total structure for jet fighter, piston cargo, and jet bomber-type aricraft, assuming constant gross weight and constant performance.

Fig. 11 illustrates the range improvement with factor of safety reduction for jet fighter and jet bomber-type aircraft. In this case, gross weight is assumed constant with the weight reduction in structural components being utilized by adding fuel to the airplane. This permits all the performance characteristics to remain the same with the exception of the improvement noted in the range of the airplane due to the increased fuel.

Figs. 12 and 13 illustrate the performance variation with decrease in load factor for jet fighter, piston cargo, and jet bomber-type aircraft. In this case, the original airplane configuration is retained and fuel is kept constant, but the gross weight is decreased because of the structural weight reductions.

Fig. 14 illustrates the increase in pay load (fuel and armament or cargo) with reduction in factor of safety. The greatest gain is for a fighter since the per cent of gross weight in useful load is the lowest for this type of aircraft.

The previous illustrations have all been based on a given configuration wherein the gains shown have been from the weight savings in the structural components. However, the greatest advantage from a reduction in the factor of safety is obtained for an airplane in the proposal stage when a growth weight factor is considered during the determination of the configuration. Growth weight factor is defined as the weight increase in power plant, fuel, structure, and equipment to carry one additional pound of weight and still maintain a given performance.

Fig. 15 illustrates the weight variation with factor of safety for an elastic configuration considering the performance as being constant and an assumed growth weight factor of seven. Considering the cost of the air-frame weight as being $35 per pound, and the air-frame weight of a fighter-type aircraft as being 50 per cent of design gross weight, Fig. 16 shows the savings in initial investment costs with factor of safety variation for 100 airplanes.

In addition to a reduction in the original investment of an airplane designed for a factor of safety of less than 1.5, the annual operating costs are also reduced, as illustrated in Fig. 17, for an interceptor fighter-type aircraft. Operating costs are defined as costs for fuel, facilities, man power, and other miscellaneous items for operating an aircraft in flying status. Here, again, it is assumed that configuration is elastic and that aeroelastic effects and structural behavior remain unchanged above the limit loadings. Actually, the reduction will not be quite as great as indicated since repair and replacement costs have not been included. Such repair and replacement costs are dependent on the probability of exceeding design limit load factors and the possible nonlinear behavior of the structure and aeroelastic effects. However, there is some definite saving in operational costs with a reduction of factor of safety, and, for some aircraft, these savings may be large compared to the initial investment in the aircraft. Why not use some of this apparent saving in initial investment costs and operating costs to improve our structural knowledge with the further refinements and investigations we have been talking about so that a realistic factor of safety can be used?

Conclusions

In this discussion, I have tried to point out that there have been appreciable advancements in structural knowledge even though design of airplanes is still not an exact science. I have also tried to point out briefly what we attain with the present required factor of safety. Lastly, I have tried to point out some of the economic gains when a reduction in factor of safety is considered. No doubt there are many arguments that can be presented by individuals who might feel that safety is jeopardized if some reduction in factor of safety is considered at this time. There has been no attempt to suggest having less safety than exists on present-day aircraft. On the contrary, as it has been shown in my discussion, it may be necessary to increase the present value of the factor of safety in some cases in order to obtain the safety we think we have. The present basic philosophy of optimism in the structural analysis and design of composite multiload path structures should continue. Furthermore, it is necessary to continue, for economic reasons and future growth, the basic philosophy of conservatism in design of single load path structures, main structural members such as wing and tail attachment fittings, large forgings, and similar critical parts. However, I firmly believe there are certain design aspects wherein a reduction in the present required ultimate factor of safety is realistic and should be considered, and there are other design aspects wherein a reduction should not be considered at this time. These can be placed in the following two categories:

Category A—Structure affected by the following points shall be placed in this category, and a reduction in ultimate factor of safety should not be considered at this time.

(1) When operational requirements of a new aircraft are not definitely determined, and design maneuvering, landing loads, and loading distributions cannot be definitely ascertained "within small tolerances."

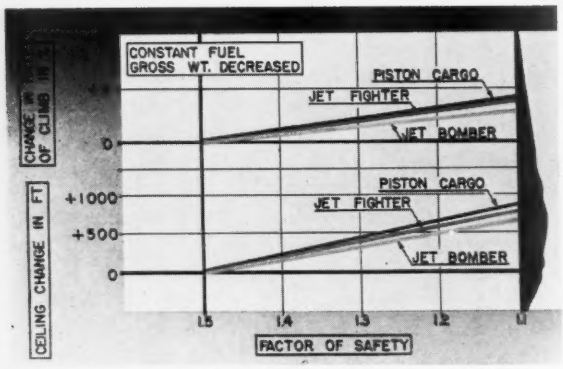

FIG. 12. Effect of factor of safety on ceiling and climb.

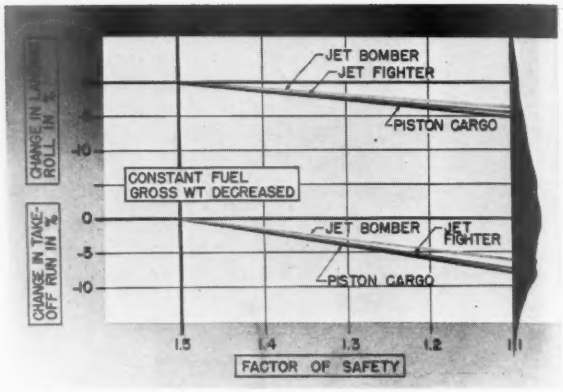

FIG. 13. Effect of factor of safety on take-off and roll.

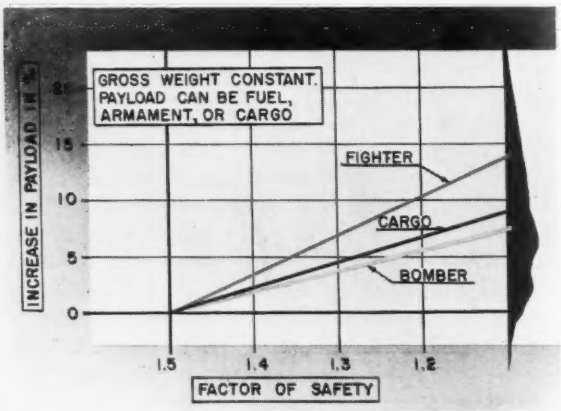

FIG. 14. Effect of factor of safety on pay load.

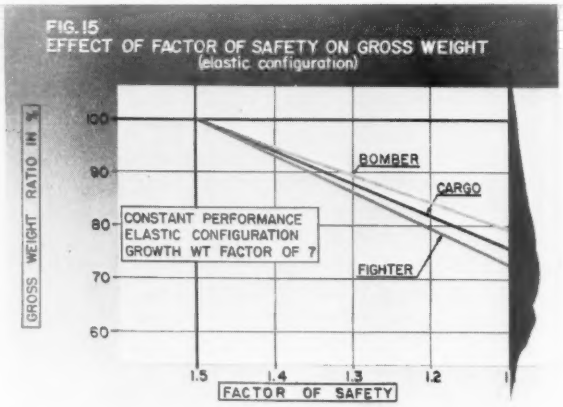

FIG. 15.

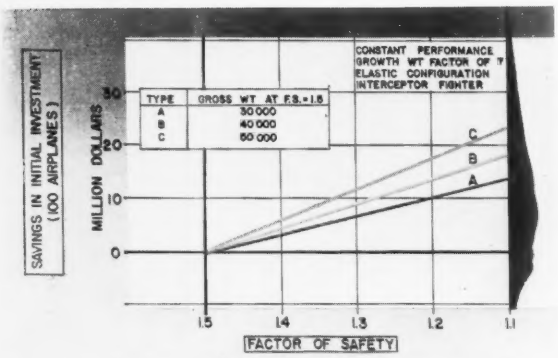

FIG. 16. Savings in initial investment costs vs. factor of safety.

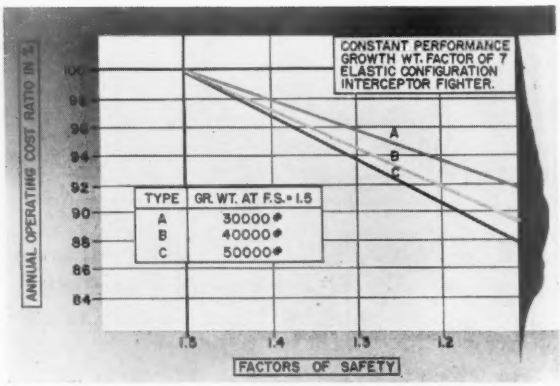

FIG. 17. Reduction in annual operating costs vs. factor of safety.

(2) When positive steps are not taken to prevent exceeding the specified design limit maneuver load factors by a large amount inadvertently due to undesirable low stick force in pounds per *g* and unduly light control forces in general.

(3) When adequate experimental data are not available for use in design and prior to delivery of aircraft.

(4) When structural behavior due to aerodynamic heating or other phenomena cannot be accurately determined.

Category B—Structure affected by the following points shall be placed in this category and a reduction in the ultimate factor of safety should be considered at this time. In all instances, adequate consideration must be given to fatigue requirements.

(1) Loadings resulting from ram pressures. These can be ascertained fairly accurately.

(2) Loadings from pressurization, such as in pressurized cabins or hydraulic systems. Such loadings are controlled by a pressure relief valve and cannot be exceeded unless malfunction occurs. It may be more economical to install a dual relief system than to provide excessive strength in the structure for such malfunctions.

(3) Thrust loadings from engines and booster rockets. These loads are determined accurately and therefore cannot be exceeded.

(4) When 1.5 times the limit loads encountered in maneuvers result in ultimate load factors on the airplanes greater than 1.5 times the limit design load factors.

(5) When 1.5 times the limit loads encountered in gusts result in ultimate gust velocities on the airplane considerably in excess of any probabilities of attaining such gusts.

(6) When loadings are limited because of the buffet boundaries of the airplane. However, proper consideration must be taken of the magnifications of the loadings when the buffet boundaries are reached and even exceeded.

(7) When loadings are due to negative pressures approaching absolute vacuum.

(8) When loadings are due to true terminal velocity that cannot be exceeded.

(9) When loadings are due to hinge moment limitations. Many control surfaces, such as flaps, ailerons, all flying tails, etc., have hinge moment limitations due to the available power of the hydraulic operating cylinder. Therefore, the maximum available hinge moments on these surfaces cannot be exceeded. If adequate tolerance is provided to the center of pressure of the loadings on the surface, then the limit load is the maximum load possible on the surface. In fact, in many cases, overall wing, tail, and fuselage critical loads and airplane load factors cannot exceed limit values because of such hinge moment limitations.

(10) When practical installations of *g*-limiters and gust alleviators are available. In such cases, limit loadings cannot be exceeded. However, malfunction of such installations should be taken into consideration.

(11) When automatic controls are installed on aircraft for maneuvering operations. Here, again, the loading conditions will be restricted to the specified maneuver loadings. This method of operation is already in use on pilotless aircraft, and the criteria of an ultimate factor of safety of less than 1.5 have been accepted with considerable structural success.

The above items I have listed are by no means all the items that can be put in this category. I have tried to list some of the main items that would contribute to a lighter designed airplane if a reduced factor of safety were considered. Structure designed in this category should be designed for no perceptible permanent set or yield below the limit loading conditions (BuAer excepted since a minimum yield factor of safety of 1.15 over limit load is specified). With the use of the high strength aluminum and steel alloys, the ultimate factor of safety should be the ratio of the ultimate strength to the yield strength of the structure. However, this ultimate factor of safety should have a minimum value commensurate with the safety considered necessary during the operational life of the aircraft.

I know there is considerable inertia against a change because of precedent. Design philosophies have changed with the advent of pilotless aircraft. I believe that design philosophies will change considerably for both military piloted aircraft and commercial aircraft and still retain satisfactory safety if good engineering judgment is applied.

I propose a challenge to the aircraft designer of the future. Is the present required factor of safety realistic? My answer is *No*. Therefore, let us try to make it realistic if we intend to build airplanes more economically and just as safe in the future.

APPENDIX A

Required Factors of Safety for Design of Civil Aircraft*

As indicated in the 1929 issue of Aeronautics Bulletin No. 7-A, *Airworthiness Requirements of Air Commerce Regulations*, factor of safety was defined as follows:

Factor of Safety—The ratio of the design load or the ultimate load to the maximum probable load. In airplane design, the least factor of safety is usually 2. The term is often used incorrectly in place of load factor.

At that time, the required factor of safety was included in the load factor specified for a given design condition—i.e., ultimate load factors were stipulated in each specific instance. Additional factors of safety (now referred to as multiplying factors) for details of the primary structure, such as fittings, were also specified as considered necessary or were provided for by the required assumption of efficiencies of less than 100 per cent for certain items or elements. This philosophy of ultimate load factor requirements continued through

* Information submitted by George D. Bogert and Armer M. Alcorn, Civil Aeronautics Administration, Los Angeles Regional Office.

the 1933 version of Bulletin 7-A, although the specific definition of factor of safety was last contained in the 1932 edition.

With respect to the load factors to which the factors of safety were applied during the period ending 1933, the original maneuvering load factors were based upon actual accelerations obtained in flight manuevers; the tests were made by the Army Air Corps in the years preceding the beginning of civil air regulation in 1926. To avoid establishing categories or weight classifications, the commercial load factors were made to depend on gross weight and power loading. Up until 1932 the design load factor was given by a chart based upon these two variables. In 1932 this chart was modified by increasing the load factors for airplanes with low power loading, the revisions consisting in changing the slope of the lines on the load factor chart, starting at a power loading of 12. The factors were not changed for power loadings greater than 12.

In 1934 the requirements were revised considerably in form. The main object of this revision was to introduce certain basic performance and design characteristics without appreciably changing the status of existing airplanes. This was done mainly by means of empirical equations for design speeds, adjusted to agree with previous practice. No substantial change in the maneuvering load factors was introduced in the 1934 version, as the studies of this subject had not revealed any system that seemed to be entirely suitable. It was realized that the existing load factor charts neglected the important characteristics of wing loading and drag loading (cleanness). These were covered to some extent, however, by the adoption of gust load factors (which depended on wing loading and speed) and by the inclusion of the drag loading in the gliding speed formula. (This took care of the torsional loads on the wing.)

The maneuvering load factor charts were replaced by an empirical equation that gave a smoother transition but did not change the load factors appreciably. The minimum value of design load factor was dropped from 4.0 to 3.75 mainly because of satisfactory experience with large flying boats.

Since the 1934 revision involved a correlation of loading conditions with actual flight conditions, it was necessary to split the design load factor into two parts: an "expected" or "actual" load factor; and a factor of safety. The latter was taken as 1.5 to represent a minimum value.

The load factor obtained by dividing the design load factor by the factor of safety of 1.5 was called the applied load factor. A new requirement was added to ensure that this factor could be withstood without permanent deformation of the structure.

For your ready utilization, the actual wording of the strength requirement in the 1934 edition of Bulletin 7-A was as follows:

"The minimum factor of safety for any aircraft structure or component therefore shall be of 1.50 unless otherwise specified. This requires that the ultimate strength of any member shall be at least 1.50 times as great as its critical applied load."

Coupled with this basic strength requirement were the following definitions:

Applied Load Factor—The applied load factor is, in general, the actual acceleration in terms of g, the acceleration of gravity, expected to be applied in a given flying or landing condition. It represents the ratio between the total loads in the accelerated and unaccelerated conditions.

An applied load factor of n acting in a given direction, therefore, indicates that the actual total external load acting on the airplane in that direction is n times the weight of the airplane. In such an accelerated condition (with no angular acceleration), each item of mass in the airplane exerts a force on the structure equal to n times its own weight and in a direction parallel to and opposite to that of the external load.

Applied Loads—The applied loads are the actual loads, either external or internal, produced by a specified loading condition. External applied loads are usually expressed as unit loading in pounds per square foot in the flying conditions. The internal applied loads may be expressed directly in pounds or converted into applied shear, bending or torsional moment, or unit stress.

Design Loads—The design loads are equal to the applied loads multiplied by the total factor of safety.

Factor of Safety—The factor of safety is an arbitrary factor by which the applied loads or load factors are multiplied for the purpose of ensuring sufficient strength to permit the applied loads to be exceeded by a definite amount before complete failure of the structure occurs. In general, the factor of safety also provides sufficient strength to prevent permanent set under the applied loads. The total factor of safety may include special factors to ensure extra strength or rigidity in certain cases.

Margin of Safety—The margin of safety is the percentage by which the ultimate strength of a member exceeds the design load for the member.

The applied stress in any material shall not exceed the yield point. In general, the minimum factor of safety specified in this section is sufficiently high to provide for this.

In accordance with this 1934 definition of factor of safety, it was necessary to check the applied load against the yield allowable only when the ratio of the ultimate allowable stress of the material to its yield allowable stress was greater than the ultimate factor of safety specified.

In 1938 Aeronautics Bulletin No. 7-A was replaced by Part 04 of the Civil Air Regulations, in keeping with adoption of the Civil Aeronautics Act of 1938. In that first edition of CAR 04, the terms *design* and *applied* were replaced by *ultimate* and *yield*, respectively, both of these terms referring to loads required to be withstood by the structure. A new term, *limit*, was introduced to specify the actual or expected load factor, and that limit load factor was considered to represent the

value for which an airplane was expected to be completely airworthy. It therefore represented a definite flight limitation for airworthy operation. The term limit, incidentally, was adopted by agreement among the Army, Navy, and Bureau of Air Commerce as a result of work accomplished by the ANC Committee on Aircraft Requirements.

Another minor change was included in the 1938 edition of the CAR 04: Whereas additional multiplying factors for items, such as fittings, were included in the factors of safety stipulated in the 1934 Bulletin 7-A, the basic required factors of safety were divorced from the multiplying factors in CAR 04. This, however, was not a fundamental change and represents the current manner in which the relationship between limit loads and the required ultimate design loads for any and all structural elements is expressed.

The basic design requirement philosophy of the 1938 edition of CAR 04, insofar as factors of safety are concerned, has been retained to date throughout all of the intervening versions of civil airplane airworthiness design requirements.

APPENDIX B

Required Factor of Safety for Design of Aircraft (USAF)*

The second and third editions of the *Handbook of Instructions for Airplane Designers* do not indicate a factor of safety but instead show respective strength factors for wings, fuselage, and tail surfaces of the various types of aircraft in existence at that time. The date of the second edition is February, 1921.

The first reference to the factor of safety appears in the fourth edition, dated April, 1925, and reads as follows:

"The ratio of the design load, or the ultimate load to the probable maximum load. In airplane design, the least factor of safety is usually about 2.0. The term is often used incorrectly in place of load factor; design and ultimate being the same."

The fourth edition still quotes factors based on an ultimate strength requirement. However, the factors are increased over those of the previous editions, indicating that the factor of safety and definition of limit load as known today were coming into existence.

The factor of safety remains the same through the seventh edition of the *Handbook*. However, in Revision 6, dated March, 1934, to this edition, the figure was changed from 2 to 1.5. This date supports the general thought of today that the value represents the spread between yield and ultimate of 17ST.

Past service experience has dictated the necessity for such a value, and we are in no position to vary from our present requirement. Justification of this value today would be accomplished through a discussion of fatigue, operation of aircraft in excess of design, material variances, manufacturing techniques, and other items that are well known.

* Information submitted by Lt. Col. John K. Bussey, USAF, Asst. Chief, Structures Branch, Aircraft Laboratory, Directorate of Laboratories, WADC.

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The Application of Flight-Test Techniques to Air-Load Distribution and Structural Research

VERLYN G. MARTH*
Douglas Aircraft Company, Inc.

ABSTRACT

A structural flight-testing procedure has been devised to furnish data concerned with aircraft air-load distribution and structural integrity evaluations. This paper treats in qualitative form the equipment and techniques utilized in a typical flight-test program that combines the data furnished by strain gages, deflection cameras, and pressure pickups. Some test results are shown for an actual wing structure. The pressure distribution technique using automatic data-reduction methods is compared with the strain gage network method for determination of loading distribution. Instrumentation for a typical test program is discussed, and a new high-capacity pressure selector valve is described.

INTRODUCTION

THE COMPLICATING EFFECTS of aeroelasticity and Mach Number on air loads and the importance of accurate definition of load distribution for optimum structural efficiency have placed an increased emphasis on measurement of component loads, strains, and deflections in flight. Although a flight-test program devised to accomplish this purpose generally involves considerable cost and effort, the benefits derived from the test results have, in some instances, been such that broadened structural evaluations are being incorporated into the flight-test program of aircraft prototypes where their configuration and/or operating range are advanced well beyond the experience of the industry. For these cases it may be considered justifiable to establish detailed structural and aerodynamic load characteristics in contrast to the procedures formerly used wherein structural evaluations were normally in the form of a demonstration, with the load factor, Mach Number, control deflections, and dynamic pressure being incrementally increased until design values were reached.

These characteristics of bending moment and displacement, shear, surface twist, component strains, and pressure distribution are of value for several purposes. In the interest of safe conduct of the structural demonstration, the flight-test values may be compared directly to the equivalent terms established during static tests. Any radical deviation between flight- and static-test results at comparable points in the flight envelope are an indication that the theoretical loading is in error to some degree. If the difference is large enough, a reapplication of static loading, using the values established in flight, would be desirable. On some contemporary aircraft the final static test is to be delayed until flight-test values of loading are available for all of the most critical loading conditions. If this procedure is followed, the airplane will be flown at the test air speeds over a range of load factors below limit load factor and the data extrapolated out to the conditions required for the static test to limit and, finally, ultimate load factor. With such close relationship between flight-test and static loading, the data-reduction methods must be simple and rapid to prevent an excessive lag in the static-test program and the flight-test structural demonstration. A delay to either program can be quite costly, particularly when production models follow closely behind the prototype.

Another important use for the data obtained from flight structural research tests on a new aircraft is to confirm or modify the theoretically predicted flight loads. New plan forms and Mach Number and aeroelastic effects have combined to make the load distribution estimations increasingly difficult and make the availability of comparison between theoretical and experimental results extremely desirable in the transonic and sonic areas. As aircraft performance moves into the range where temperature effects grow in importance, it is logical to assume that the new aircraft configurations will demand continued and even expanded investigations of this air-load problem. However, these investigations must be carried out in a manner that will not result in a delay to the particular aircraft's production programs. A program paralleling but not necessarily preceding production may be indicated.

PROCEDURES

Several means are available for air-loads research. One of the first to be used both in wind tunnels and on full-scale aircraft has been the measurement of the pressure field surrounding bodies or lifting surfaces. The principal advantage of the system is that loads are measured directly. If used properly, it can not only determine overall loading but, in addition, readily obtain detailed information concerning local loads. The disadvantages of the system are the large data-reduction time for the mass of data needed to define a distribution with high accuracy and the difficulty encountered with lags during transient phenomena.

* Flight-Test Engineer, Testing Division.

In spite of these disadvantages, innumerable tests, by both Government research groups and private agencies, have provided detailed load information to the designer. A typical test of this nature is described by Garvin.[1]

Strain gage instrumentation has established itself as a valuable tool of the test engineer. In the field of flight tests this device has been useful as an indication of component strain on complex structures, for definition of loads and moment applied to control surfaces, for giving an indication of force in simple truss systems or fittings, and as a device for defining flutter and other transient effects. More recently, methods have been introduced to calibrate numerically the outputs of several strain gage bridges in a manner that permits shear loads and bending moments to be obtained directly.[3, 4]

The procedure that has been evolved for several test programs conducted by the Douglas Aircraft Company's Testing Division to obtain detailed structure and air-load information is a combination of the methods described. In general, it consists of a safety comparison of flight strains with those obtained by analysis and static test, measuring structural deflections by cameras, and a pressure survey on the structure to establish local air loads and overall load distribution. In special instances where total shear and moment are required during rapid transients, such as fin or horizontal stabilizer loading, the matrix evaluation of a bending and shear gage combination on the skin and spars is used, or more preferably, the loads are directly taken out of gaged attach fittings.

Although all the techniques described above have been used individually and in combination, pressure distributions are favored for extensive air-load programs. These pressure data are combined with limited surveys by the other flight-test methods to present a useful comparison with static-test and theoretical structural analysis.

Factors Influencing Selection of Strain Gage or Pressure Survey Methods

There are several reasons why precedence has been given to the pressure survey in lieu of the combined strain gage technique for air-load data. One of the strongest objections to pressure probing has been the time-consuming operations required during data reduction. By means of the instrumentation and methods described later, the bulk of the data-reduction effort has been assigned to automatic computers, greatly decreasing man-power requirements. This makes practical the installation and reduction of sufficient points to give a complete and accurate load distribution. The system furnishes direct air-load results and does not require that inertia loads be calculated and combined with the test data. Fuel consumption from wing tanks does not have a first-order effect on the pressure readings or zeros. With a pressure survey it is not necessary to take time from the normally tight flight schedule to conduct a sampling and calibration program as is required with the strain gage method, nor is the associated loading test jig required.

Difficulty is often encountered with temperature effects on strain gage networks. Where the structure is in a constant temperature environment during test recording and during preflight and postflight zeroing and calibration, the material that is gaged becomes adequately "temperature soaked," and no problem exists when temperature-compensated gages are installed. However, solar radiation, rapid change of ambient temperature in a dive, and temperature transients accompanying rapid Mach Number changes of high magnitude introduce large unknowns into the strain gage method. During Douglas Skyrocket tests in dives to the highest Mach Numbers, stagnation temperatures and local structure temperatures were subject to such fluctuations that it would appear the ground calibration of any strain gage network would have been invalidated or at least difficult to apply.

Some further complications result from gage failures, particularly partial failures, during the course of a test program: the possibility of permanent set in the gaged material as testing approaches or slightly exceeds limit load and the complications accompanying an attempt to define any detailed spanwise distribution. The advantages, on the other hand, are simplicity of data reduction once the calibration is accomplished and the ability of the strain gage to record transients with high frequency resolution. The transient problem is usually one of response following an abrupt rudder and elevator control displacement, the most adverse loading for vertical and horizontal tail surfaces. One approach to this problem, outside of the strain gage network method, is to define the pressure field around the surface for steady-state sideslip and pull-up conditions and combine these results with safety strain gage readings on local structure and total tail load from attach fittings taken during rapid transients. Inertia loads must, of course, be removed from the latter data.

Some agencies have successfully devised pressure surveys useful during transients by incorporating principles of minimum line volumes and high frequency response transducers. Generally this means that a small strain gage transducer is located directly at a flush orifice. Some problems to be overcome with such a system are transducer installation and replacement difficulties, reduction or maintenance of hundreds of transducer gain factors, and, unless a summation is used, the necessity of reduction of several points during the transient to ensure coverage at the peak load point. These factors are not insoluble, however, and the system has definite promise for the future.

Comparison between the results of the strain gage and pressure distribution methods, obtained from an actual flight test of a conventional aircraft configuration, has generally indicated acceptable agreement.[5]

Application

Pressure surveys have been utilized successfully on the Douglas D-558 Phase II research airplane, the

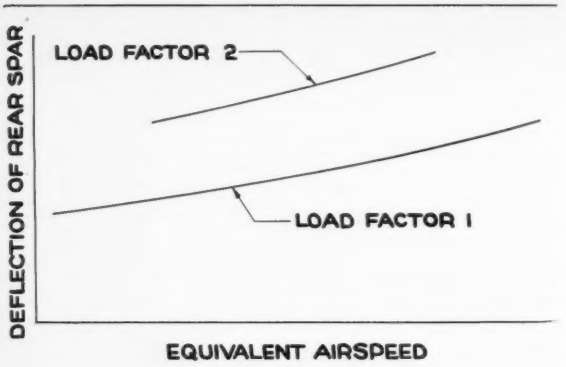

FIG. 1 Wing deflection variation with air speed at a load factor of 1.0 and 2.0.

C-124, and the X-3 and are contemplated for a number of future applications. Most of these surveys of pressure fields are closely allied with safety strain gage installations or gage networks that permit shear and moments to be measured directly. Although the pressure-recording details and the complexity of application have varied from project to project, the principles are similar. To illustrate a generalized procedure, several nondimensional curves and records established on C-124 tests are reviewed.

During dives to high speed on the C-124, it had been established from strain gage safety instrumentation that the wing strains were increasing with air speed while flying at a constant load factor. A series of flight tests was subsequently conducted to define in detail the air-load and structural characteristics of the airplane. Instrumentation for the test consisted of a wing pressure survey installation, a number of wing structure strain gages, a wing bending and twist deflection camera, a strain gage network on the rear of the fuselage giving total tail load, and a normal complement of detail instrumentation such as air speed, control positions, and angle of attack. For pressure distribution 12 spanwise stations were surveyed on one wing, with 20 orifices at each station. Additional pressure pickups were installed along nacelle and fuselage centerline and at radial points about the nacelle and fuselage. Instrumentation, program details, and test results are described by Hann.[2]

Fig. 1 shows the increase in wing deflection with air speed. Curves of the two load factors show that the change is substantial, with the deflection at high speeds and load factor 1 equal to that at low speeds and load factor 2. The data are those measured from a ground zero and would be corrected to a zero weight wing before comparing directly with static-test results. Fig. 2 shows spanwise structural deflection points measured in flight tests by a wing deflection camera. The data shown are for constant air speed and, again, ground zeros are taken as a reference. Accuracies in the order of 1 per cent of maximum deflection are obtainable. Comparative data for a typical strain gage station are shown in Fig. 3. The actual test points are presented as an indication of the degree of scatter in safety strain gage information. The strain variation with the product of gross weight and normal load factor is linear.

An example of consistency of pressure distribution data is shown on Fig. 4. The plots include the surface pressure at an upper and lower orifice plotted in terms of $\Delta P/q$ versus local angle of attack. The data that were taken on several different runs show good repeatability.

Fig. 5 shows the pressure distribution over the upper surface of a wing as defined by means of pressure survey. To separate the lines of constant $\Delta P/q$, the spanwise dimension has been foreshortened. Data presented in this form must be reduced to the $\Delta P/q$ on the upper and lower surface for each station and the gradient manually determined and plotted. Since reducing and fairing such data is time consuming, a simple normal force coefficient form is used for most loading conditions. Integration of the section pressure distribution reduces the data to the form of local normal force coefficient versus spanwise station, as shown in Fig. 6. Spanwise shift of the center of pressure with air speed and increase in down tail load with air speed accounted for the increasing strains and deflections previously discussed. These data were taken for several test conditions, extrapolated to design conditions, and applied as a static-test article loading.

The balancing tail-loads variation with air speed was shown to add an appreciable increment to the load the wing must lift. In the case of the C-124, there is a static variation of over 15,000 lbs. with center of gravity, weight, and equivalent air-speed change. This load was defined by a strain gage network during the air-load test program, and this determination was complemented by a series of dynamic tail-load tests. Horizontal surface loads during transients induced by elevator pulses were evaluated by Fourier analysis to reduce the results from total load, in the time domain, to aerodynamic tail load, in the frequency domain.

Instrumentation Considerations

Pressure Distribution Applications

A Douglas-designed pressure selector valve was first installed in the D-558 Phase II research airplane. The purpose of the installation was primarily to define supersonic pressure distribution about a lifting surface rather than as a means for complete air-load determination. Two wing stations, with 34 pressure flush orifices at each station, were monitored. Another research airplane, the X-3, has facilities for a relatively complete pressure survey, utilizing the NACA-developed 24-cell manometer unit recording on 6-in. sensitized paper. It has the advantage of being mechanical in nature and having high recording capacity but operates with rather small trace deflections.

The C-124 test program consisted of an extensive pressure survey, using a completely redesigned pressure selector combined with external strip-a-tubing for orifices and lines. Both are described in detail later. In addition to fuselage and nacelle surveys, 12 wing sta-

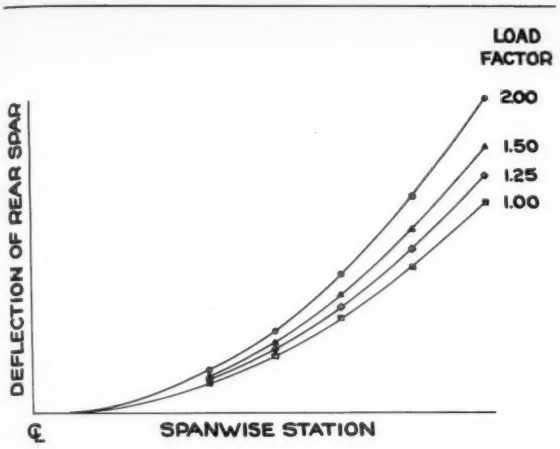

FIG. 2. Wing spanwise deflection distribution for several load factors at a given equivalent air speed.

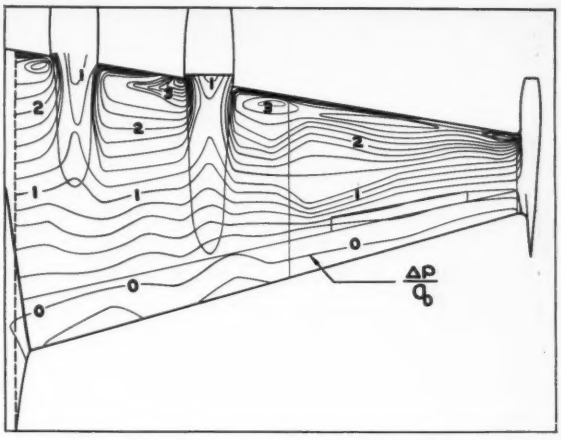

FIG. 5. A typical upper wing surface pressure survey.

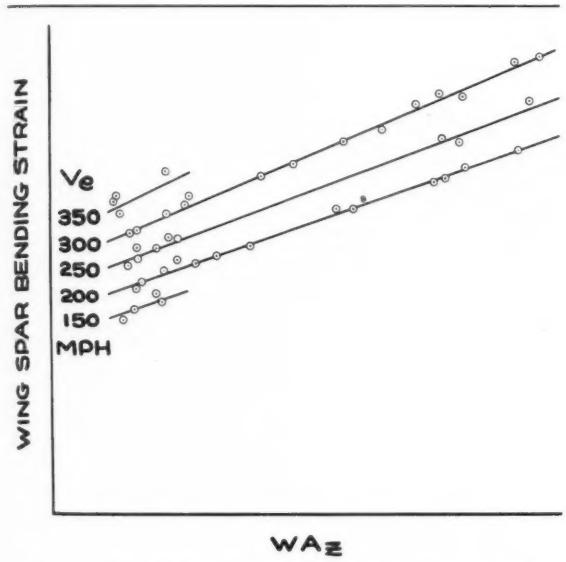

FIG. 3. Wing strains versus the product of gross weight and load factor for several equivalent air speeds.

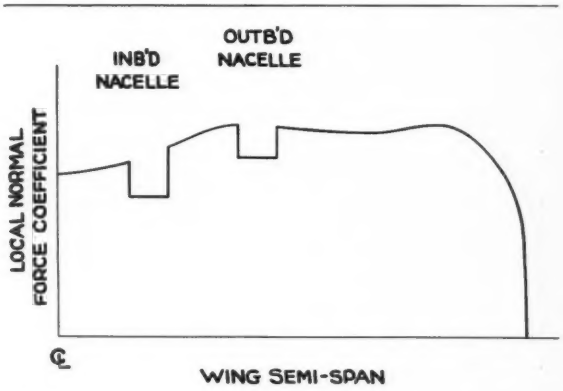

FIG. 6. Local normal force coefficient over the wing semispan.

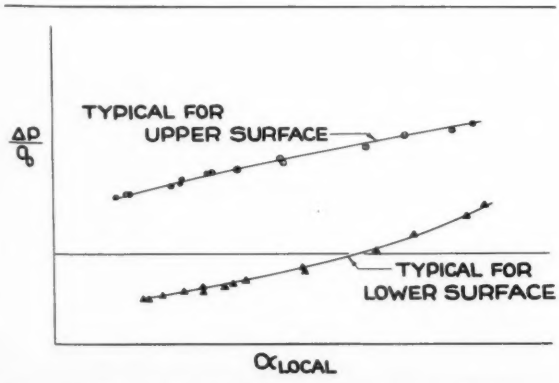

FIG. 4. Lifting surface local pressure coefficient variation with local angle of attack.

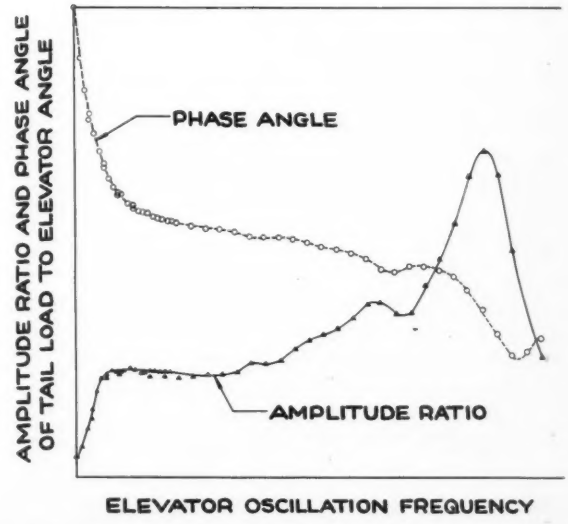
AMPLITUDE RATIO AND PHASE ANGLE OF TAIL LOAD TO ELEVATOR ANGLE
PHASE ANGLE
AMPLITUDE RATIO
ELEVATOR OSCILLATION FREQUENCY

FIG. 7. Transfer function of the aerodynamic tail load to elevator input.

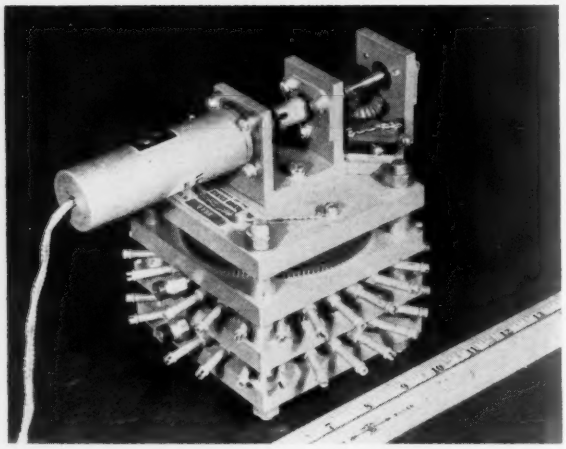

FIG. 8. Pressure selector valve.

tions were investigated on one wing, at the following chordwise percentages:

Upper Surface	Lower Surface
1.25	0
2.5	2.5
5.0	5.0
7.5	10.0
10.0	25.0
15.0	40.0
25.0	60.0
40.0	65.0
60.0	90.0
75.0	...
90.0	...

The percentage planes selected should be dependent on the airfoil section of the surveyed wing or empennage. On aircraft designed to operate in the transonic range where the lifting surface pressure peaks are shifted aft, it is advisable to increase the orifice density over the center and rear portion of the chord.

Because of the effects of spanwise flow on the pressure readings over externally installed strip-a-tubing, flush orifices may be preferred for swept wings. From an aerodynamic standpoint, there is little to choose between installing a flush orifice section parallel to the flight direction or normal to the sweep axis on the wing. The alignment of orifices may be best dictated by installing them parallel to the rib structure to avoid internal interferences.

Pressure Selector Valve

Fig. 8 shows the pressure selector used to monitor successive pressures in a pressure survey. It consists of two banks, each having 23 input fittings and one output fitting. In most applications each bank is assigned a complete lifting surface station. Depending upon pressure line and flight characteristics, a motor and gear train is installed to provide a cycling period of from 2 to 6 sec. for sampling the 23 orifice pressures.

The pressure selector is built on a close tolerance shear seal valve principle and consists of a carbon ring with a single hole rotating over a fixed steel plate having 23 pressure inlets. The plate and the ring are held in contact by a spring force, and no lubrication is used between the units. Leakage is minimized by "superfinishing" the two surfaces in contact flat to within 2 bands of monochromatic light and smooth to less than 2 microin. root mean square and by designing a structure rigid enough to eliminate deflections from accelerations and pressures. Resultant leakages are insignificant for the sampling times normally used.

Pressure Lines

A fundamental rule concerning lines in any pressure survey system is to keep lines as short as possible. Inside diameter is not too critical if transient pressures, such as elevator distributions, are not to be recorded, since with lines up to 30 ft. long and diameters between 0.10 and 0.25 in., acoustic lag and lag due to pressure change with altitude are not large enough to require correction. However, length of the orifice line and volume in the pressure selector and in the line between the selector and the transducer have an appreciable effect on stability and response following a pressure pulse. The most favorable condition is to have the transducer attached directly to the pressure selector and to limit the line between the orifice and the stepper to a minimum length.

A rather extensive laboratory lag, response, and stability program was completed on a simulated pressure survey system. Fig. 9 is a typical example of the effect that line length has on trace deflection following a square wave pressure pulse input. Response and frequency of oscillation are reduced as line length is increased.

In addition to the lines going to the stepper, a pressure from one of the test orifices is usually recorded directly on a continuously recording channel and also monitored by a gage in the crew compartment. Such an arrangement facilitates the pilot's holding constant the angle of attack, and was found to permit him to anticipate changes in the test-indicated air speed. It also provides a direct indication of steady-state conditions during data reduction and a check of the magnitude of a pressure indicated by the selector valve-transducer system.

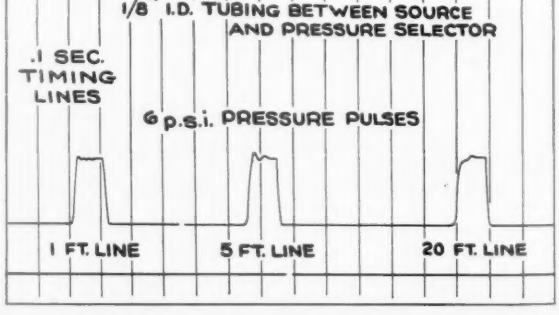

FIG. 9. A typical pressure selector system response to a pulse transient.

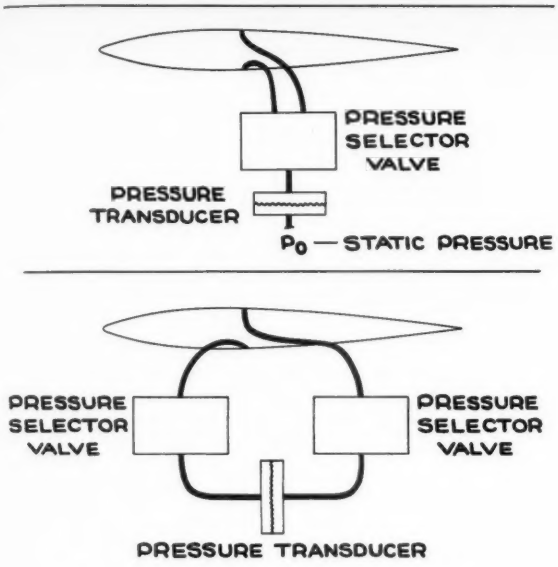

FIG. 10. Transducer-selector valve combinations.

Orifices

The strip-a-tubing previously mentioned consists of a plastic extrusion of a flat section one line deep and $3^1/_4$ in. wide. The inside diameter of each of the 13 interior circular passages is 0.10 in. and the overall thickness approximately 0.18 in. A wedge-shaped integral filler on both sides of the belt fairs out the rectangular cross section. The strip-a-tubing is cemented around the particular section being surveyed and at desired percentage points, a sharp-edged orifice is cut through to one of the interior channels, and a filler seal is installed on one side of the hole.

Tests have shown that pressures recorded by strip-a-tubing in areas where cross flow is not present are comparable to pressures recorded by flush orifices in the same area and at the same flight conditions. Aircraft have been operated at 470 knots equivalent air speed with this tubing on the wing surfaces, and higher speeds are considered feasible.

Flush orifices are generally installed during construction of the airplane, since accessibility in some areas is limited. A countersunk screw with an orifice in the center is installed through the skin to a pressure line fitting inside the structure. Leakage checks and lag checks should be completed coincident with installation of the orifices and lines in closed areas, and the open orifices should be sealed between flights to prevent entry of water or other foreign matter into the lines.

Transducers

The pressure transducers found to give good results in the pressure selector system are high-response, low-volume, strain-gage units recording on an oscillograph. The range required is, of course, a function of the maximum $\Delta P/q$ predicted for a particular test condition. To minimize zero error and trace noise level, it is important that the pressure pickup have little or no response to accelerations or temperature changes.

Two arrangements for combining the pressure selector valves and the transducers are shown in Fig. 10. The first is used where individual plots of upper and lower pressure distribution are required. Reduction time is simplified if orifices are installed on the same percentage plane on the upper and lower surface of a wing and the differential pressure between them recorded as shown in the lower schematic. With this arrangement, lag effects in the air-speed static system are eliminated from consideration and recording channel requirements are halved. Loading distributions are defined to the same degree by both methods, but local pressure gradients are not obtainable using the second scheme.

Structural Deflection Cameras

Aircraft component deflections in flight have been successfully measured by cameras with 16 mm., 35 mm., and 4-in. by 5-in. negatives. Experience has indicated that a 35-mm. motion picture camera is readily adaptable to such measurements if a proper lens is selected. Every precaution must be taken to eliminate small angular displacement of the camera mount. In the case of the C-124, this requirement was met by using a heavy, unloaded frame fabricated from I beams and angle iron. If such a framework is supported at three or four points well removed from each other, the effects of deflection on angular displacements will be small.

Targets on the structure should be of high contrast for adequate resolution on the film. Most installations to date have been in the form of small metal tabs attached to structures with an adhesive. Small, high-intensity lights, recording on continuously moving film, have been used by the NACA.

The scale used for bending data reference is established by taking a ground shot of a surveyor's stadia rod at each station. With a data-reduction device, such as the Telecomputing Corporation Telereader, the zero and scale may be set up so that the full scale deflections are read rapidly and accurately. Both strain gage and deflection values determined from ground zeros must be corrected to a zero weight wing condition. Either appropriate biasing values must be computed from

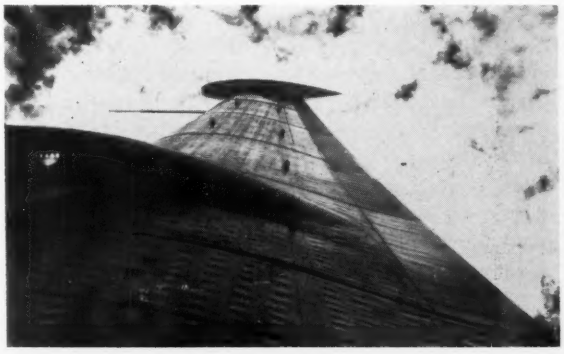

FIG. 11. Photograph from a wing bending camera during a high load factor turn.

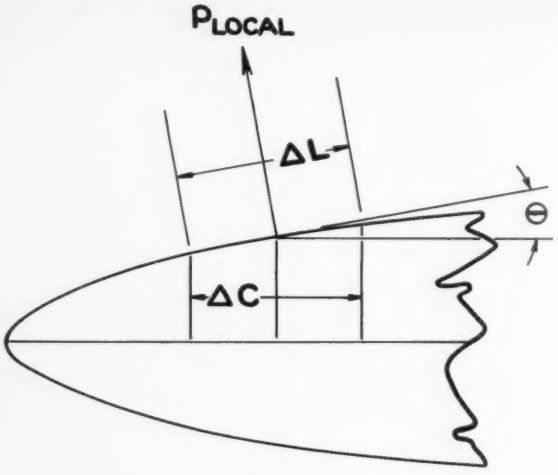

FIG. 12.

structural characteristics and mass loading, or the test data may be extended to zero load factor and zero dynamic pressure to define references.

Twist angles may be computed from deflections. Less scatter, however, was obtained by reading angles with a Bausch and Lomb Comparator. This is a magnifying optical device having a vernier scale on which angles can be read to 1 min. with respect to a hairline reference.

A photograph of the C-124 wing taken from one of the bending cameras during a high load factor condition is shown in Fig. 11. Note the deflection targets and bands of strip-a-tubing for pressure surveys.

Pressure Distribution Data Reduction

Fig. 12 shows a section of a lifting surface. The normal force, with reference to free air static on the unit-width element shown, is equal to

$$\Delta F_{\text{local}} = \Delta P \Delta L \tag{1}$$

Where

$$\Delta P = P_{\text{local}} - P_0 \tag{2}$$

the force normal to the chord on an element of unit width becomes

$$\Delta F_{N\text{local}} = \Delta P \Delta L \cos\theta \tag{3}$$

but

$$\cos\theta = \Delta C / \Delta L \tag{4}$$

therefore

$$\Delta F_{N\text{local}} = \Delta P \Delta C \tag{5}$$

and

$$F_{N\text{local}} = \left(\sum_0^c \Delta P \Delta C\right)_{\text{upper}} + \left(\sum_0^c \Delta P \Delta C\right)_{\text{lower}} \tag{6}$$

If the pressure pattern is surveyed by taking the upper and lower pressure differential as shown in Fig. 11 and

$$\Delta P' = P_L - P_U \tag{7}$$

then

$$F_{N\text{local}} = \sum_0^c \Delta P' \Delta C \tag{8}$$

For either case

$$C_{N\text{local}} = \frac{F_{N\text{local}}}{qC} \tag{9}$$

where

q = dynamic pressure

and

$C_{N\text{local}}$ = local normal force coefficient

The operations of Eqs. (6), (8), and (9) are readily adaptable to IBM machine computation. The individual orifice pressures in terms of oscillograph trace deflection may be established with the aid of an optical-mechanical reader. These ordinates are punched on IBM cards and tabulated along with point and run identification and trace gain factor. The integration is handled by the automatic computer operating on the punched-card data. If the quantity of data warrants the machine set-up time, the dynamic pressure term in Eq. (8) may also be computed from air-speed system characteristics and from the air-speed and altimeter readings for a particular run.

The introduction of automatic data reduction radically decreases the magnitude of effort required for evaluation and eliminates the major objection to pressure survey methods. Shortly after a flight test is completed, data in the form of a local C_N distribution are made available for analysis.

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The Self-Contained Airplane*

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Boeing Airplane Company

Abstract

This paper presents, from the manufacturer's point of view, a discussion of self-containment for large turbine-powered airplanes. It includes some of the more important obstacles to, and the advantages of, self-containment. An airplane that is fully self-contained can operate completely independently of ground power.

Particular emphasis is placed on this degree of self-containment. If the bleed air from the main engines cannot be used for air conditioning because of contamination, the independence that self-containment offers could be obtained for little or no loss in airplane performance. This paper suggests a system that would satisfy this requirement and refers to it as a basic accessory power system. The performance and operations cost factors for lesser degrees of self-containment relative to this basic accessory power system are also discussed. The conclusion states that the manufacturer can measure airplane performance for any degree of self-containment, but that it is still up to the operator to determine what degree of self-containment may best suit his particular application.

Introduction

Self-containment of the turbine-powered airplane has become an issue with the airplane manufacturer and the operator as well. They would both like to have it. But the trouble is that neither has been able to justify it for anything other than installations where self-containment is more important than a loss in airplane performance. The airplane manufacturer, obviously, will not proceed with a self-contained airplane design unless he feels that it is the best solution. By the same token, the operator will not buy the airplane unless he feels that he can operate it at a profit. There must be an optimum combination of airplane and ground equipment costs. Profit to an air line is in terms of dollars. Profit to the military is in terms of air mobility, pay load, and range. Self-containment plays an important role in each of these applications and deserves careful consideration. This paper discusses a particular self-contained accessory power system that would result in little or no loss in airplane performance. This system is referred to as the basic accessory power system. The costs of lesser degrees of self-containment are related to this basic system. An attempt is made to show the major points that must be resolved if self-containment is to be justified.

Presented at the Accessory Design Problems Session, National Summer Meeting, IAS, Los Angeles, June 21–24, 1954.

* The opinions expressed in this paper are those of the author and do not necessarily reflect the opinions of Boeing Airplane Company.

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Definition

What is the self-contained airplane? It is an airplane that can operate independently of ground sources of power. (See Figs. 1–3.)

Advantages

It is difficult for the airplane manufacturer to weigh the advantages of self-containment in terms of dollars. Just what is a reduction in ground congestion worth to an operator? Any reduction in the amount of ground equipment around an airplane should increase the efficiency of operations and reduce both the turn-around time and the overhead in equipment and man power. Ground handling damage to the airplane would also be reduced. Uninterrupted heating or cooling of the cabin, prior to and after passenger loading, should have definite sales appeal. The ability to check out all the airplane systems before starting the main engines would reduce turn-around time as well as ground time on the main engines. The main engines could be started whenever the airplane is ready for departure. In the event that noise and pebble aspiration make it desirable to tow the airplane to take-off position, full accessory power and cabin air-conditioning requirements would be met without interruption. The same is true, of course, if the airplane taxis from the flight apron to the take-off position. Another advantage while taxiing would be that main engine power settings would not have to be monitored to maintain accessory power. Centralization of the accessory power system should simplify maintenance for both the accessories and the main engines.

Self-containment through the use of pneumatics offers a number of advantages from a maintenance point of view. Air is available anywhere in the world, it is safe because it does not burn, it is simple to use because it requires no return system, it is light in weight and gives rapid response, and, above all, it is clean. Furthermore, there is no need to worry about anyone's putting the wrong fluid in. Self-containment gives flexibility to operation. The airplane does not have to park at a particular spot on the flight apron. It can operate from any suitable field in the world without being dependent on the ground equipment available. Self-containment creates an ideal commercial or military airplane from an air mobility point of view. A whole fleet could move on short notice without being concerned about ground equipment.

The in-flight advantages of a self-contained or pneumatic system are easier for the manufacturer to weigh

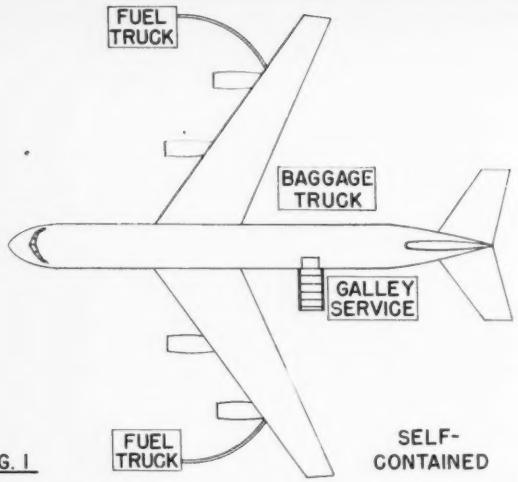


FIG. 1

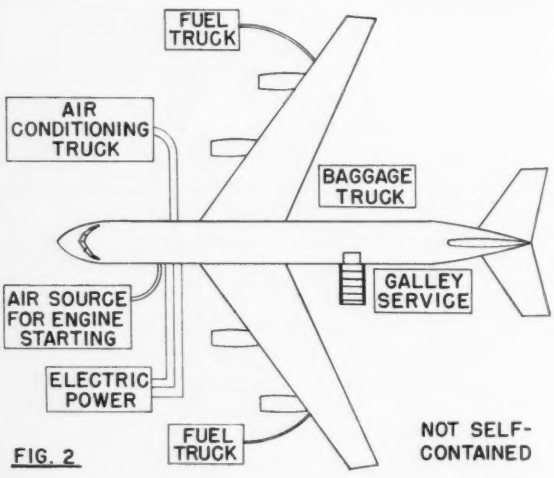


FIG. 2

SELF-CONTAINMENT PROVIDES ACCESSORY POWER FOR:

A. ENGINE STARTING
   1. PNEUMATIC STARTER
B. THE AIR CONDITIONING SYSTEM
   1. HEATING
   2. COOLING
   3. VENTILATING
C. THE HYDRAULIC SYSTEM
   1. CHECK FLAPS AND CONTROLS
   2. PRESSURE TO LANDING GEAR
D. THE ELECTRIC SYSTEM
   1. LIGHTING
   2. ELECTRONICS
   3. FUEL PRESSURE
   4. COCKPIT CHECK

WITHOUT BEING DEPENDENT ON GROUND POWER EQUIPMENT

FIG. 3

because they can be measured in terms of fuel—that is, their net effect on airplane performance. One difficulty, however, is that the equipment required for full self-containment, as discussed in the following basic accessory power system, has not been developed to the point where an airplane manufacturer would care to commit an airplane design to its use. (See Fig. 4.)

The Basic Accessory Power System

It is contended that a system having universal acceptance must not reduce the overall airplane performance from either the manufacturer's or the operator's viewpoint. The particular system suggested here is intended to be the one that could most easily be justified.

A hot surface is defined here as any surface whose temperature exceeds 450°F.—that is, a surface that represents an autogenous ignition hazard in the presence of fuel and/or oil vapors. It is obvious that, if we are to have any degree of efficiency in an accessory power system, there must be some hot surfaces exceeding this limit. Energy must of necessity be derived from some fuel, preferably the same type of fuel used by the main engines. Before proceeding with self-containment, it must therefore be agreed that the accessory power system can be installed in such a manner as to offer no appreciable increase in fire hazard. Adequate ventilation of both the equipment and ducting areas would appear to be the best solution. Autogenous ignition of fuel and oil vapors will not take place unless they are allowed to be heated above 450°F. One approach is to shroud all combustion chambers, nozzle boxes, and exhaust ducts. Cool air would then be passed between these shrouds and hot surfaces as has already been done on a number of current production units. This results in the lowest possible shroud surface temperature. In addition, the shroud or enclosure will contain a possible fire and make an ideal environment for extinguishing it. The accessory compartment in which these power units are placed should be unpressurized and should have positive ventilation whenever the equipment is operating. Positive ventilation should also be provided in the areas through which engine bleed air ducts pass if main engine bleed air temperatures exceed 450°F.

Ideally, airplane performance should not be reduced by incorporating self-containment. Every advantage must be taken to improve accessory system efficiency and reduce installed weight. Pneumatics is an ideal means of transferring energy in an airplane that is to be fully self-contained. The installation and environment for pneumatics, however, must allow adequate exploitation of its characteristics. It is imperative, from the manufacturer's viewpoint, that justification for any combination of airplane accessory power systems must first be made on an energy basis—that is, the first question he must have answered is: How much of the fuel carried in the airplane tanks is chargeable to the accessory systems, and how much is left to propel the

THE OBSTACLES TO SELF-CONTAINMENT ARE:

A. HOT SURFACES ABOARD AN AIRPLANE
   1. AUTOGENOUS IGNITION
   2. VENTILATION

B. AIRPLANE PERFORMANCE
   1. FROM MANUFACTURER'S VIEWPOINT
   2. FROM OPERATOR'S VIEWPOINT

C. EQUIPMENT LOCATION
   1. CENTRALIZATION
   2. HAZARDS

D. EQUIPMENT COST AND AVAILABILITY
   1. STATE OF DEVELOPMENT
   2. SELF-CONTAINED VERSUS GROUND EQUIPMENT COSTS

FIG. 4

airplane? Ideally, we should be able to account for all the fuel consumed. An integrated accessory system may consist of air-conditioning, hydraulic, electric, and anti-icing systems. We cannot compare two air-conditioning systems and consider that we have compared two integrated accessory systems. Selection of an accessory power system for best airplane performance cannot be made on an energy basis alone. The manufacturer must furnish the prospective operator with the performance and characteristics of a number of accessory power system arrangements. It will then be up to the operator to determine which arrangement best suits his particular application.

Accessory system integration through the use of pneumatics may serve to keep down the total installed weight. The reason for this is that the only connection between the engines and the accessory power system is the main engine bleed air duct system. This duct system can supply energy from any one or all of the main engines. The duct system weight can be kept down by careful consideration of the thermal and air pressure loads. The number of expansion joints or loops should be kept to a minimum. If bleed air pressures are regulated at each engine, duct and duct support weights can be kept to a minimum. The net amount of energy lost in regulating the flow will be small because regulation will take place only during take-off and climb. Full bleed pressure will be allowed in the ducting system during cruise and descent because the regulated pressure will not be exceeded. Energy can be conserved by insulating the bleed air ducts and by using bleed-burn and variable area nozzles in the power units themselves. Each accessory power unit would be duplicated for safety's sake, and each duplicate pair would deliver power for both in-flight and ground use. There would be no auxiliary power units as such. The combination of engine bleed air and the accessory power units would furnish all the energy required by the airplane systems. This includes electric, hydraulic, air-conditioning, anti-icing, and engine-starting systems and any specialized loads such as air turbine-driven aerial refueling pumps.

Equipment location will also affect total installed weight and, in turn, airplane performance. Ideally, the accessory power system should be designed into the airplane and located centrally so that the overall weight of the system can be kept to a minimum. (See Fig. 5.) But, in most airplanes, a central location would fall just forward of the wing center section and result in the loss of some baggage, cargo, or bomb bay space. Hence, the equipment space must be considered at the inception of an airplane design. It may also be argued that a central location offers a fire hazard during refueling operations. This may be especially true with centralized single-point refueling. The safety of center section fuel tanks has been questioned, however. In addition, outer wing panel refueling points should not offer any greater fire hazard than if the accessory power units were located in the empennage and the refueling point was in the center section.

From a noise standpoint it is felt that both the inlets and outlets from the accessory power units will have to be equipped with silencers, or their locations will have to be such as to offer no nuisance noise during passenger loading. It is not felt that noise through the cabin floor will be a particular problem.

The accessory power system considered here for the self-contained airplane will at present cost in dollars more than any other system. It must be considered, however, that this is a new approach to accessory power and that a great deal of developmental work remains to be done. Self-containment, through the use of auxiliary power equipment, started with the reciprocating engine-driven generator and has since progressed to the turbine-driven APU as power requirements have gone up. In each case this equipment represents additional costs in both dollars and airplane performance. Nevertheless, its use has been accepted for the special-purpose airplane. The potential for the completely integrated system, through the use of pneumatics, has hardly been scratched. With recent developments in equipment design it should soon be possible to show that this approach costs in terms of fuel less than any other accessory power arrangement.

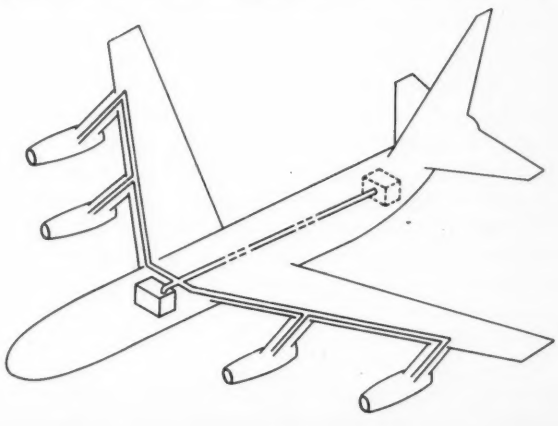


FIG. 5

This will be especially true if the possibility of main engine bleed air contamination remains such that fresh air will be required at all times for the air-conditioning system. The cost of the airplane equipment is offset somewhat by the cost of the ground equipment required for the turbine-powered airplane that is not self-contained. In some cases ground equipment now on hand for the reciprocating-engined airplanes may not be adequate. Any new ground equipment purchased represents a sizable increase in overhead. Utilization of such equipment may be low.

The auxiliary power unit in today's self-contained airplane may be a reciprocating engine-driven generator, a gas turbine-driven compressor, generator, or alternator, and would never be expected to operate much over a 20,000-ft. altitude. It is usually idle equipment for the major portion of a flight. Its weight represents an additional fuel cost. It can be justified, however, because it gives the airplane mobility. It enables the airplane to operate from any field or harbor in the world without being dependent on the ground power equipment available. The commercial airplane, on the other hand, can operate only from a limited number of airports. The problem, then, becomes one of weighing ground equipment costs against the loss of airplane performance due to self-containment. The problem is similar for the military airplane except that, in that case, pay load and range are weighed against air mobility.

Auxiliary power, as it is presently used, represents a major step in the advance toward the fully integrated accessory power system. Fig. 6 shows a schematic diagram of a system that might provide self-containment without a loss in airplane performance. It will be noted that the heart of this system is an accessory power unit that delivers compressed air (a gas turbine-driven air compressor). The air compressor on this unit would be required to supply fresh air to the air-conditioning and pneumatic systems. During flight, the turbine drive on this unit would operate as bleed-burn or, in case of a burner failure, as a direct bleed air unit. It would be equipped with variable area nozzles to give the highest efficiency and the lowest air consumption. The speed of the unit would be variable depending on air demands. For ground operations, this unit would furnish air to the air-conditioning system, the accessory drives, main engine starters, and the thermal anti-icing system. The entire airplane pneumatic system would be pressurized by these accessory power units. For in-flight operation, main engine bleed would provide all the energy required by the accessory drives and the thermal anti-icing system, as long as the bleed pressure exceeded that of the accessory power unit compressor. The accessory drive would operate at constant speed and would deliver power to an alternator, hydraulic pump, and refrigerant compressor if required. Part of the energy required by the accessory power unit turbine would be furnished by the main engine bleed. The balance would be obtained by burning fuel to heat this bleed air before it enters the turbine. From a net energy cost standpoint both the accessory drives and the power units could be operated most efficiently as bleed-burn. If the power unit should fail completely, engine bleed air could be furnished directly to the air-conditioning system. The air-conditioning system could be simple cycle, bootstrap, or vapor cycle. The choice would affect the performance required of the power units. If simple cycle, the pressure ratios would have to exceed 5:1 at sea level, whereas 2:1 might be adequate for a bootstrap system. Another consideration, however, is main engine starting time where pneumatic starters are used. A 5:1 pressure ratio may be most desirable. This pressure ratio in conjunction with the mass flows required by the air-conditioning system would provide ample energy for fast engine starts. This same pressure ratio would be approximately correct for the accessory drives and for a regulated pneumatic duct pressure.

Degrees of Self-Containment

The basic accessory power system discussed above was based on the assumption that main engine bleed air would be contaminated. If main engine bleed air can be used directly in the airplane air-conditioning system, the alternate air source will not be required. The accessory power units then used to accomplish self-containment will be limited in their application. In addition, their use will undoubtedly result in additional fuel cost to the airplane.

An auxiliary gas turbine-driven air compressor could furnish ground power to all the airplane systems as was done in the basic system above. This is suggested as the next most logical accessory power arrangement for self-containment. The unit would not be used throughout a flight because of altitude limitations. Another variation on the gas turbine-driven air compressor would be to have it deliver shaft power to an alternator or generator. This would provide a slightly higher degree of self-containment as far as the power unit itself is concerned. Power provided by this equip-

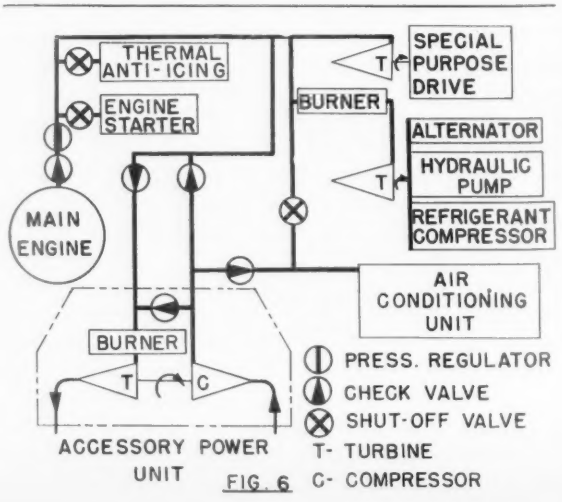


FIG. 6

ment while the airplane is on the ground would take care of air conditioning, electric loads, and engine starting. It could also be used as auxiliary or stand-by power during take-off and landing. A power unit that delivers shaft power only could not take care of air conditioning and engine-starting loads. Self-contained starters could be used, but they are heavier than a pneumatic starter installation. There may also be a logistic problem in providing them with special fuel. They do eliminate the need for a source of ground power, if the airplane batteries can furnish enough energy for fuel pumping and ignition during engine starting. Once the main engines are started, electric and hydraulic energy could be furnished by direct drive and air for air conditioning by direct bleed.

No Self-Containment

The airplane that has no self-containment is entirely dependent on the ground equipment available. The cost of ground equipment for turbine-powered airplanes may be quite high, especially if new ground air-conditioning equipment, electric alternators, and an air source for pneumatic starters are required. In some instances self-containment for the airplane may cost little more than the new ground equipment that would be required. The ground power unit could be used on only one airplane at a time, it requires at least one man to run it, and it requires storage and maintenance. Utilization may be extremely low. If the operator of the turbine-powered airplane intends to operate from more than a limited number of airports, his investment in ground equipment, or overhead, may soon reach sizable proportions.

Conclusions

Justification for any self-containment arrangement must be based on two things:

(A) Operating efficiency in terms of fuel or energy.
(1) Fuel chargeable to the accessory systems.
(2) Balance of fuel left to propel the airplane.
(B) Ability of the operator to use it to a profitable advantage.
(1) Sales appeal.
(2) Cost of self-containment.
(3) Reduction of operating costs.
(4) Flexibility of operations.
(5) Reliability.
(6) Safety.

Fourth General Assembly of AGARD

(*Continued from page 49*)

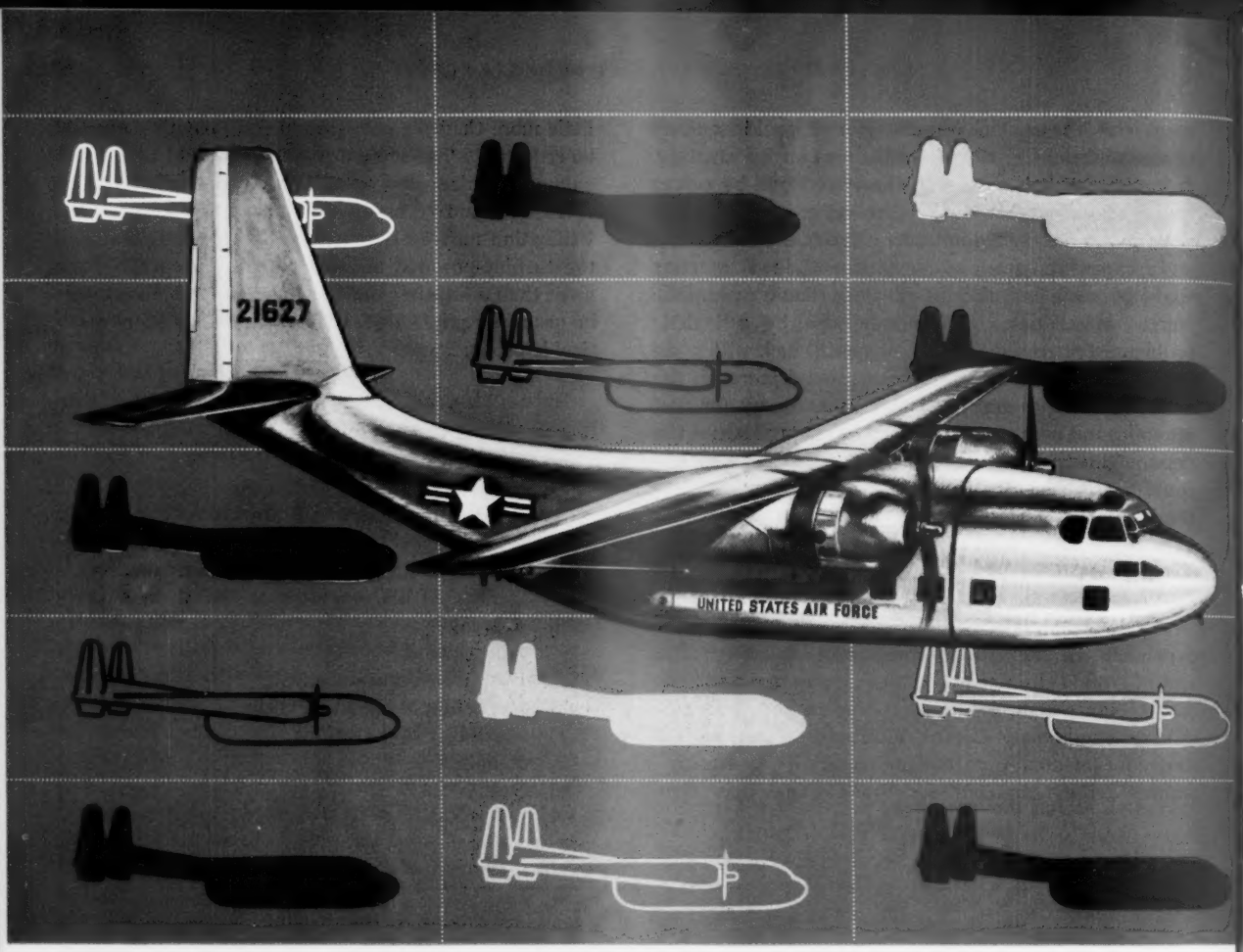
strumentation permits the pilot to do something about it. . . .

Most of the problems that I observed in my service in the Navy and since which were attributed to pilot fatigue were, to my mind, largely a result of boredom. So many operations have been taken away from the pilot in the modern airplane that, unless he is doing some specific task, he tends to go to sleep on the job, as many of us do when we are just sitting. . . .

Another thing that appalls us is that the problems of stability and control are highly nonlinear and the trends often reverse. I cannot solve a nonlinear differential equation and not many black boxes can, but pilots daily do so by instinct, intuition, and common sense. . . .

The real problems that are limiting to us personally as pilots are truly medical problems. Deafness seems to be a chronic professional disease of pilots. You can tell a pilot's age by whether he cups one hand or two hands to his ears. There, too, is the problem of sinus blockage under large pressure changes. We have (as has been quoted) diving rates of 60,000 ft. per min. Decompression and subsequent recompression by pressure suits serve terrific shocks to the ears and sinus. In my own case, I have occasionally been forced into blindness by the pain of sinus blockage. These are some of the particular aeromedical problems that are facing the pilot and the industry. About the time you have a man qualified to fly these airplanes, he is just about gone as far as his ears and sinus are concerned. He hates to admit it, but he then begins to allow himself the luxury of psychological problems. His flying time diminishes from year to year, and soon his contribution is lost to the industry.

That brings up these much referred to physiological and psychological problems. The physiological problems affect me psychologically and the psychological problems affect my physiological endeavor. . . . What is the difference between the physiological and the psychological problems, and how may the pilots contribute to the solution of these problems?



FLYING BOXCAR AND AVITRUC TEAMED FOR MILITARY AIR TRANSPORTATION!

Close to full-scale production at Fairchild — the new C-123 Assault Transport will fill specialized military requirements for an air transport sufficiently versatile to deliver men or equipment at advanced bases. This sturdy craft readily converts from a carrier of 60 fully equipped combat troops to a cargo plane delivering more than 15 tons of equipment.

Continuing quantity production of the combat proven C-119 Flying Boxcar assures the nation that our military transport program is completely flexible. This dual production brings closer the day when C-119's and C-123's will be in regular use as a part of the U. S. Air Force and U. S. Army military operations.

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IAS News

(*Continued from page 39*)

old W. Dodds, President, Princeton University. Of the eight men selected, six are being awarded new Fellowships, and the remaining two have had their Fellowships renewed for an additional year.

Those who have been awarded new grants are Robert Hirschkron; Paul Lieberman, IAS Student Member; Sau-Hai Lam, IAS Student Member; Dwight Mahaffy, IAS Student Member; Major Edward S. Wilson, USAF, TMIAS; and Lt. Guy G. Wooten, USN, TMIAS. Those whose grants have been renewed are Sinclaire M. Scala and Andrew F. Burke.

The announcement of the five persons who received Guggenheim Fellowships for advanced study and research at the Guggenheim Jet Propulsion Center at the California Institute of Technology was carried in the July, 1954, issue of the AERONAUTICAL ENGINEERING REVIEW. The Guggenheim Jet Propulsion Center at Princeton and the one at CalTech were both established in 1948 by The Daniel and Florence Guggenheim Foundation. To date, the two Jet Propulsion Centers have given graduate training to more than 100 engineers.

Necrology

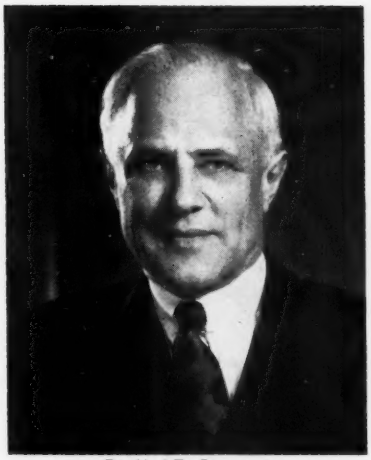
Dr. Karl T. Compton

Dr. Karl Taylor Compton, IAS Fellow and Founder Member, Chairman of the Corporation, Massachusetts Institute of Technology, died in New York Hospital, New York, on June 22.

The son of a Presbyterian minister, Dr. Compton was born on September 14, 1887, in Wooster, Ohio. He attended the College of Wooster where he received a Ph.B degree in 1908 and an M.S. in 1909. He worked on his doctorate at Princeton University and was awarded his Ph.D. degree in 1912. During the past 30 years, he was the recipient of many honorary degrees.

He entered the academic field in 1909 as a Chemistry Instructor at the College of Wooster. After taking his Ph.D. at Princeton, he joined the faculty of Reed College as an Instructor in Physics. In 1915, he became a member of the faculty at Princeton University, remaining there until 1930. During the intervening 15 years, he served successively as Assistant Professor of Physics, Professor, and Research Professor and Chairman of the Department.

In 1930, Dr. Compton was appointed President of Massachusetts Institute of Technology. He remained in this position until 1948 when he was elected Chairman of the Corporation, M.I.T.



Dr. Karl T. Compton

Throughout his career, Dr. Compton served on numerous boards and committees. Among these are included Member, National Defense Research Committee of the Office of Scientific Research and Development, 1940–1946; Chairman, Joint Chiefs of Staff Evaluation Board on Atomic Bomb Tests, 1946; Chairman, President's Advisory Committee on Universal Training, 1946–1947; Member, Atomic Energy Commission Personnel Security Review Board, 1947–1948; and Chairman, Research and Development Board, National Military Establishment, 1948–1949.

C. J. Stewart

Charles John Stewart, AFIAS, Consulting Engineer and Managing Director, Stewart, Broadhurst, Ltd., England, died recently in Pitlochry, Perthshire, England.

Mr. Stewart was born in Portsmouth, England, on November 23, 1881, and was educated at the Royal College of Science. At the beginning of World War I, he joined the Royal Engineers (Territorial) and subsequently the Royal Flying Corps. He was discharged from the Royal Air Force in 1919 with the rank of Squadron Leader.

After receiving his RAF discharge, he became a member of the Research Staff of the Air Ministry. Some time later, he was named Superintendent of Technical Development at the Royal Aircraft Establishment. In 1938, he was appointed Director of Civil Research and Production, Air Ministry. Between 1942 and 1945, he was Deputy Controller of Production, Ministry of Aircraft Production.

News of Members

▸ **Jack M. Cherne** (M), Assistant Chief—Structures, Sikorsky Aircraft Division, United Aircraft Corporation, was elected Regional Vice-President—New England, of the American Helicopter Society.

▸ **Leon Crane** (M), Design Staff Engineer, Piasecki Helicopter Corporation, was elected Regional Vice-President—Mideast, of the American Helicopter Society.

▸ **Michael E. Gluhareff** (F), Chief Engineer, Sikorsky Aircraft Division, United Aircraft Corporation, was the recipient on June 24 of the American Helicopter Society's Dr. Alexander Klemin Award. Mr. Gluhareff was cited for "notable achievement in the advancement of rotary-wing aeronautics."

▸ **Dr. John J. Green** (F), Chief, Division "B," Defence Research Board, and Scientific Adviser to the Chief of the Air Staff, RCAF, Department of National Defence, has been elected President of the newly formed Canadian Aeronautical Institute. Dr. Green is the first person to hold this position.

▸ **Dr. R. Paul Harrington** (AF), Head, Department of Aeronautical Engineering, Rensselaer Polytechnic Institute, has been authorized by the Air Research and Development Command to continue his research into the mechanics of turbulence. The ARDC-R.P.I. contract has been extended to permit a more detailed investigation. Dr. Harrington began his work on this project in May of last year.

▸ **Lieutenant Donald M. Layton, USN** (TM), formerly an Aeronautical Engineering Graduate Student at Princeton University and now with ZP-4 NAF Weeksville, Elizabeth City, N.C., has reported that the work done at Princeton on a Master of Science Thesis, "The Longitudinal Stability of the ZP2N-1 Airship" (Princeton Aeronautical Engineering Report No. 264), by Lt. R. F. Iacobelli, USN, and Lieutenant Layton "played a part in the recent world's endurance record set by a ZP2N-1 airship."

▸ **Robert L. Lichten** (M), Project Engineer, Helicopter Division, Bell Aircraft Corporation, was elected Regional Vice-President—Southwest, of the American Helicopter Society.

▸ **Colin Hugh McIntosh** (M), Air Transportation Consultant, has been designated Special Assistant to Secretary of Commerce Sinclair Weeks. Mr. McIntosh is studying and evaluating "recent Departmental and out-

cost-cutting

stronger

more dependable

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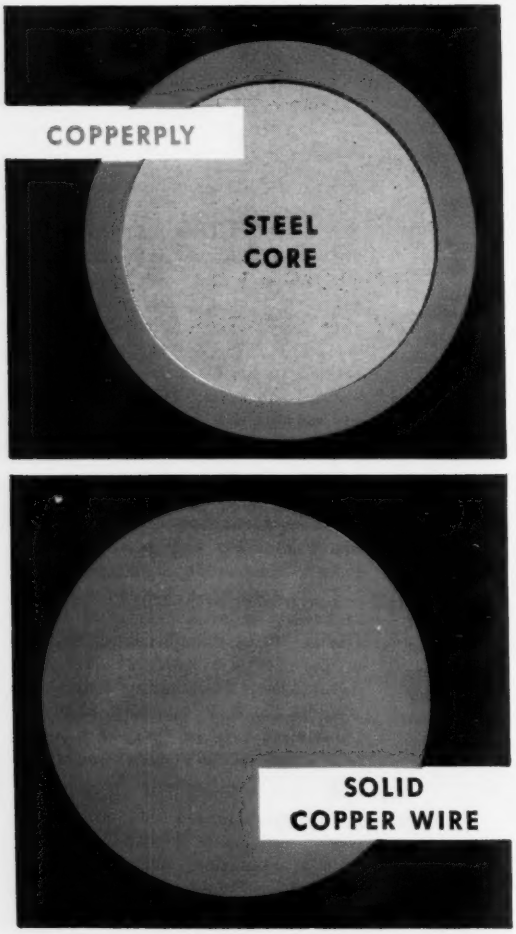
A NEW COPPER-PLATED STEEL WIRE
OF UNMATCHED NATIONAL-STANDARD QUALITY



COPPERPLY, accurately concentric and uniform, is steel wire electroplated with copper to the thickness required. This type wire was originally used for television lead-in installations. Now this unique wire is solving cost problems in many new applications.

Maybe COPPERPLY gives you ideas for applications in your field . . . uses that will result in substantial savings over solid copper wire.

In addition to cutting costs, COPPERPLY obviously is much stronger than copper wire. And National-Standard makes it with a regular or high tensile steel wire core to fill your specific requirements.

We'll "loan" you an engineer to help you develop any ideas for using COPPERPLY you'd like to explore. It's company policy to give the best service in the industry, in addition to the highest quality special wire and steel products available. Write the National-Standard Company, Niles, Michigan, concerning COPPERPLY. Write the appropriate division listed below on other products.

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Athenia Steel, Clifton, N. J.
Flat, High Carbon, Cold Rolled Spring Steel

National-Standard, Niles, Mich.
Tire Wire, Stainless, Fabricated Braids and Tape

Reynolds Wire, Dixon, Illinois
Industrial Wire Cloth

Wagner Litho Machinery, Jersey City, N.J.
Metal Decorating Equipment

Worcester Wire Works, Worcester, Mass.

Dr. Carl A. Frische, AFIAS, has been appointed Vice-President for Operations, Sperry Gyroscope Company, Division of The Sperry Corporation. He was formerly the company's Vice-President for Engineering. (See Sperry Gyroscope item in Corporate Member News.)

side management engineering surveys of the Civil Aeronautics Administration designed to improve its organization and strengthen its service to the aviation industry and public." Mr. McIntosh took over his new duties on July 5.

▸ **John K. Northrop** (F), former President of Northrop Aircraft, Inc., and now with The Garrett Corporation, received a citation and silver medal for outstanding community leadership in advancing the brotherhood of man. The presentation was made at the Sixth Annual Brotherhood Testimonial Dinner of the National Conference of Christians and Jews in Los Angeles.

▸ **Michael Stroukoff** (AF), President, Stroukoff Aircraft Corporation, recently made a grant to Mississippi State College to provide for the Larissa Stroukoff scholarships. These scholarships are to be administered by the Aerophysics Department for the prime purpose of encouraging originality in research among students of engineering, mathematics, and the physical sciences.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of IAS members. All members are, therefore, urged to notify the News Editor of changes as soon as they occur.

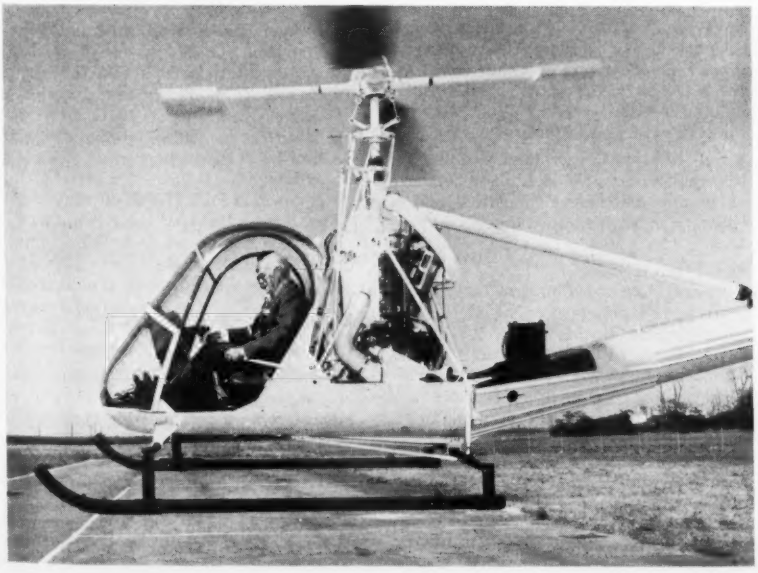
Richard E. Adams (M), Chief of Preliminary Design, Convair-Fort Worth Division of General Dynamics Corporation. Formerly, Project Engineer, Convair-Fort Worth.

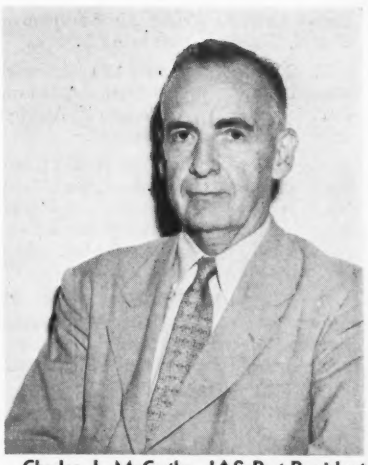
Albert W. Blackburn (TM), Engineering Test Pilot, North American Aviation, Inc. Formerly, Extended Active Duty, Captain, USMCR, Project Officer and Pilot, Armament Test, NATC, Patuxent River, Md.

Kenneth K. Bowman (M), Manager of Engineering, Guided Missiles Department, Aeronautic and Ordnance System Division, General Electric Company. Formerly, Manager, Advanced Engineering Practices, Engineering Services Division, G-E.

Edmund O. Carmody (M), President, Carmody Corporation, Buffalo, N.Y. Formerly, Contracts and Sales Manager, Stanley Aviation Corporation.

Lester D. Gardner, Founder of the Institute of the Aeronautical Sciences and an IAS Founder Member, Fellow, and Benefactor, is shown at the controls of a Hiller H23B helicopter. Accompanying Major Gardner on this flight, which was made on June 17, was James M. Meade, Test Pilot for Hiller Helicopters.





Charles J. McCarthy, IAS Past-President and Fellow, was elected Chairman of the Board of Directors, Chance Vought Aircraft, Inc., effective July 1, 1954. On that date, all ties between Chance Vought and United Aircraft Corporation were severed, and Chance Vought became an independent manufacturer of aircraft and guided missiles. It was announced that Mr. McCarthy was resigning as a Vice-President of United Aircraft, a position he has held since 1943.

R. J. Fraser (AM), Field Engineer, Heli-Coil Corporation. Formerly, Sales Engineer, Heli-Coil Corporation.

Theodore B. Garber (M), with the Guided Missiles Division, The RAND Corporation. Formerly, with Massachusetts Institute of Technology.

Seymour Gottlieb (M), Executive Assistant and Contract Administrator, Zenith Aircraft, Division of Zenith Plastics Company. Formerly, Supervisor, Military Contract Administration, and Legal Counsel, Helicopter Division, Bell Aircraft Corporation.

David Gregg (AF), Chief, Integrated Range Mission, White Sands Proving Ground, N.M. Formerly, Technical Director, Electro-Mechanical Laboratory, White Sands Proving Grounds, N.M.

H. T. Harrod (M), Assistant Sales Manager, Defense Products, Westinghouse Electric Corporation. Formerly, Manager, Aviation Sales, Westinghouse.

Harry B. Horne, Jr. (AM), Executive Vice-President and General Manager, Wallace Aircraft Corporation. Formerly, Manager of Engineering and Research, Reaction Motors, Inc.

James E. Jean (M), Group Engineer—Structures, Missile Systems Division, Lockheed Aircraft Corporation. Formerly, Design Specialist—Stress, Northrop Aircraft, Inc.

J. Aldridge Johnson (M), Department Engineer, Structures Development Department, Missile Systems Division, Lockheed Aircraft Corporation. Formerly, Group Engineer—Design, Lockheed.

Arthur L. Klein (F), Professor, Aeronautics, California Institute of Technology. Formerly, Associate Professor, Aeronautics, CalTech.

Private Sanford Lustig, USA (TM), 9301 TSU—Ord., D & P S, Det., Aberdeen Proving Grounds, Md. Formerly,

Stress Analyst, Wright Air Development Center, Wright-Patterson AFB, Ohio.

H. Charles Luttman (AF), Secretary, Canadian Aeronautical Institute, Ottawa, Canada. Formerly, Contracts Administrator, A. V. Roe Canada, Ltd.

Marshall Nesbitt (M), Assistant Executive Engineer, Santa Monica Plant, Douglas Aircraft Company, Inc. Formerly, Assistant Supervisor, Aerodynamics Section, Engineering Department, Santa Monica Plant, Douglas.

Dr. Ronald T. Probstein (TM), Assistant Professor, Division of Engineering, Brown University. Formerly, Assistant Professor of Aeronautical Engineering, Princeton University.

George J. Richard (M), Group Engineer—Loads, Missile Systems Division, Lockheed Aircraft Corporation. Formerly, Design Specialist, Preliminary and Confidential Design, Northrop Aircraft, Inc.

Anatol Roshko (TM), Senior Research Fellow, Aeronautics, California Institute of Technology. Formerly, Research Fellow, Aeronautics, CalTech.

Nevin Schwien (TM), Executive Vice-President, Schwien Engineering Company, recently purchased by William R. Whittaker Company, Ltd. Formerly, President, Schwien Engineering Company.

Romus Soucek (M), Sales Manager, Sales and Service Department, Aviation Gas Turbine Division, Westinghouse Electric Corporation. Formerly, Sales Manager, AGT Division, Westinghouse.

Raymond Vachss (TM), Section Head—Projects, Sylvania Electric Products, Inc. Formerly, with Republic Aviation Corporation.

Benedict M. Vinicky (TM), Manager, Plymold Division, Cook Electric Company. Formerly, Chief Research Engineer, Aircraft Division, Globe Corporation.

Private Saul Wasserman (TM), Aeronautical Engineer, Redstone Arsenal, Hustsville, Ala. Formerly, Aeronautical Engineer, Naval Ordnance Laboratory, White Oaks, Md.

Corporate Member News

• **Aerojet-General Corporation, Subsidiary of The General Tire & Rubber Company. . .** The company has acquired the services of Major Gen. Arthur W. Vanaman, USAF (Ret.), as a Consultant. General Vanaman came to Aerojet after 2 years in command of the Sacramento Air Materiel Area at McClellan AFB.

• **Aeronca Manufacturing Corporation. . .** The corporation announced on June 28 the sale of manufacturing rights for one of its models, namely the Aeronca Model 7 Champion. The contract covering this sale was signed with Flyers Service, Incorporated, of St. Paul, Minn., and includes the inventory, tooling, and engineering data for the Champion. It is planned by Flyers Service to set up a new organization to be known as Champion Aircraft Corporation for the production and sales of the aircraft and for sales of service parts for existing Champions. Aeronca is now devoting its entire facilities to the production and development of aircraft components.

• **Air Associates, Inc. . . .** A new self-sealing magnetic drain plug assembly, manufactured by Technical Development Company, is being distributed exclusively by Air Associates. . . .A new retail store has been opened by Air Associates at the Teterboro (N.J.) Air Terminal. This retail outlet stocks several hundred types of supplies and equipment necessary for the maintenance of commercial, corporate, and private aircraft.

• **Aircraft Radio Corporation. . .** The corporation has announced the TV-10 Transverter that extends the frequency range of ARC Type 12 VHF Airborne Communication Equipment to cover the 228–258 mc. UHF band. This UHF transmitter-converter weighs 5.9 lbs., including shock-proof mounting, and may be added to existing Type 12 installations without modifying present receivers or transmitters. A portable UHF communicator containing this unit is planned for late 1954.

• **Aviation Engineering Division, Avien-Knickerbocker, Inc. . . .** An information sheet on AVIEN's two-tube lightweight fuel gage tank unit is now available. This product is in full-scale production.

• **Beech Aircraft Corporation. . .** The U.S. Navy announced on June 17 that the Beechcraft T-34, a low-wing all-metal military trainer, has been selected for use by the Naval Air Training Command as a primary trainer. The initial order is for several hundred planes, with first deliveries expected within a year. Only a few minor changes in the basic T-34, now in production as an Air Force trainer, are necessary to meet Navy specifications. This two-place tandem trainer, which has a fully retractable tricycle landing gear, is powered by a 225-hp. Continental engine and has a top speed of 189 m.p.h. Its gross take-off weight is about 2,900 lbs. In Navy service, these planes will be painted a bright yellow, a color used by the Navy as an anticollision measure.

• **Bell Aircraft Corporation. . .** According to recent reports, the Bell XV-3 convertiplane, now under development, should be ready to make its transitional flight next May. The XV-3 has rotating rotor-propellers.

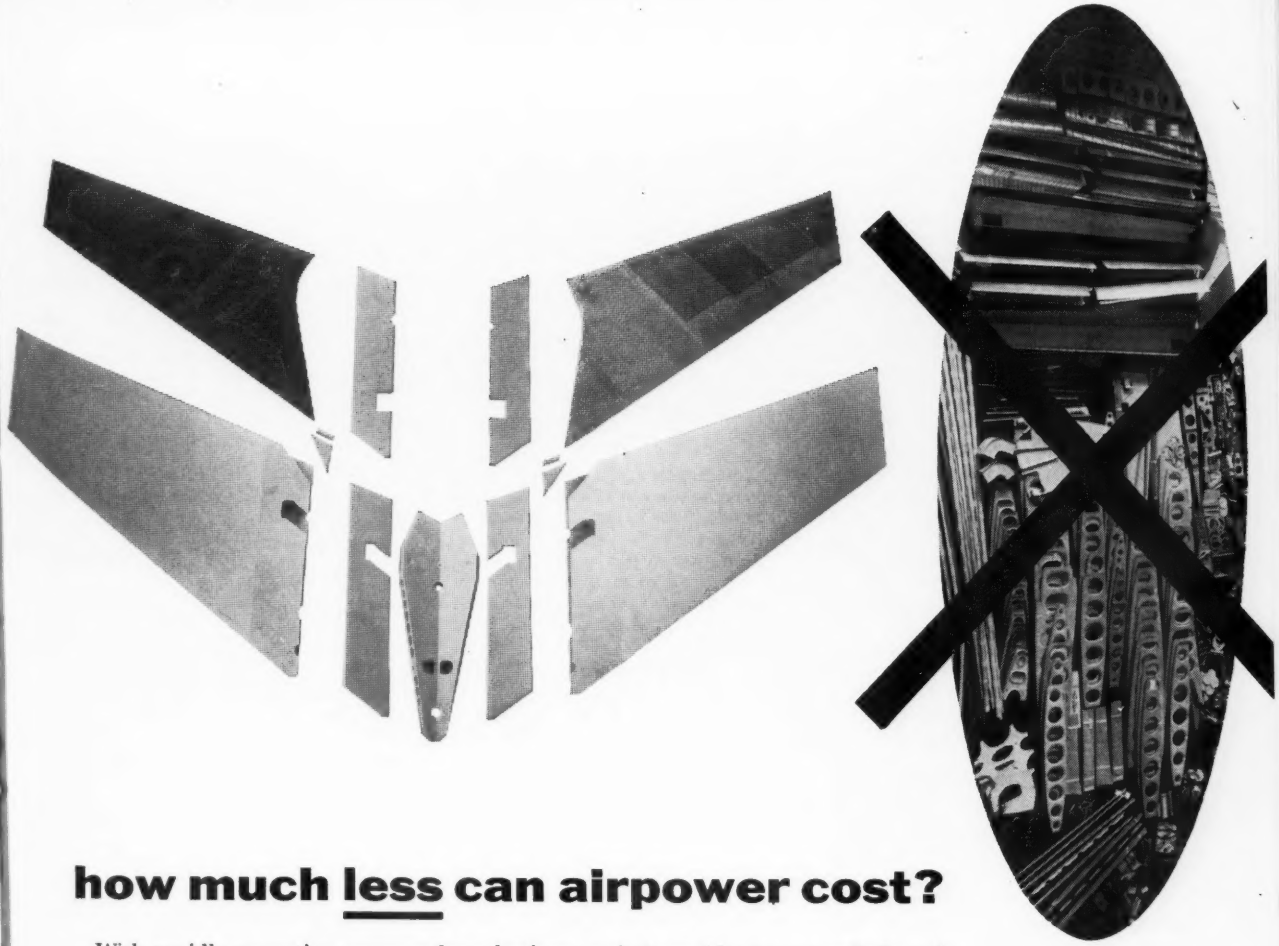
• **Boeing Airplane Company. . .** The recently announced gas-turbine engine, designated as the Boeing Model 502-10, is a development of the company's Model 502-2, which powers a variety of vehicles, aircraft, boats, pumps, compressors, and generators. The 502-10 produces a maximum of 270 hp. and has a normal rated power of 240 hp. This is an increase of 65 hp. over the earlier type Boeing gas-turbine engine. The fuel consumption in the 502-10 has been reduced by 25 per cent. The new engine weighs only 245 lbs. dry or 320 lbs. complete with lubricating oil, accessories, engine mounts, and oil cooler. It can operate on a variety of fuels ranging from commercial diesel oil to jet fuel or gasoline without modification. With inlet silencer installed, the 502-10 requires only 15 cu.ft. for installation.

• **Bristol Aero Engines Limited. . .** Air Vice Marshall A. L. James, RCAF, joined the Board of The Bristol Aeroplane Company of Canada and its subsidiary, Bristol Aero Engines Limited, on September 1. His appointment as Vice-President (Engineering) of Bristol Aero Engines Limited is scheduled.

• **Chance Vought Aircraft, Inc. . . .** On July 1, 1954, Chance Vought became a completely independent manufacturer of aircraft and guided missiles, with an independent Board of Directors and with no further legal or corporate connection with United Aircraft Corporation. This constitutes the last formal step in the execution of a proposed separation plan announced by United Aircraft last December and brings to an end an association that began in 1929 when Chance Vought joined with other aeronautical organizations in creating United Aircraft and Transport Corporation, from which United Aircraft Corporation was formed. Chance Vought operated from January 1, 1954, until the formal separation on July 1 as a wholly owned subsidiary of United Aircraft rather than one of its divisions. Charles J. McCarthy, IAS Past-President and Fellow, was elected Chairman of Chance Vought's Board of Directors. Serving with Mr. McCarthy on the Board of Directors are F. O. Detweiler, CVA President; D. A. Hulcy, Lone Star Gas Company; L. F. McCollum, Continental Oil Company; W. W. Overton, Jr., Texas Bank & Trust Company; Adm. H. B. Sallada, USN (Ret.), CVA Vice-President; R. L. Tayloe, Sears, Roebuck and Company; N. V. Turney, CVA Controller; and J. R. Wood, Southwestern Life Insurance Company. The company's elected officers, in addition to Mr. Detweiler, Admiral Sallada, and Mr. Turney, are B. W. Whitten, Treasurer, and J. J. Gaffney, Secretary.

• **Convair Division of General Dynamics Corporation. . .** The second YC-131C turboprop transport made its first test flight on June 29 at the Convair-Fort Worth plant. The YC-131C, a converted Convair-Liner 340, is powered by two Allison YT-56 turboprop engines, each developing 3,750 hp. The first YC-131C was flown at Fort Worth on May 20. . . . The National Safety Council's Award of Honor was presented to the Convair-Fort Worth Division on June 11. At the same time, Convair-Fort Worth received the Texas Safety Association's aircraft manufacturing award for companies employing more than 500 persons.

• **Cornell Aeronautical Laboratory, Inc. . .** It was reported at the June 11 annual Board of Directors meeting that "for the next several years the Laboratory plans to devote roughly fifty per cent of its potential to large comprehensive programs in critical areas of national defense, involving varied effort and drawing on the many and different talents spread throughout all of the technical departments. It is planned



how much less can airpower cost?

With rapidly mounting pressure from business and the public for tax relief—and with the airpower requirements of our security program heavier than ever before—what is our industry doing to lower the cost of taxpaid airpower?

How much less should—and can—our airpower cost?

We at Martin are daily developing dollar-and-cents answers to that explosive question, in every phase of design, engineering and production.

Shown above is a sample from the record of the U. S. A. F. Matador B-61 Pilotless Bomber, top-rated major weapon which was designed, engineered and built, from concept to acceptance, without benefit of precedent.

The stabilizer of the Matador consists of 13 parts. Shown beside it are some of the more than 3,000 parts which would be required to produce the stabilizer for a multi-engine transport by traditional methods.

What of the Matador itself? New Martin processes and methods are producing this major weapons system for a fraction of the cost-per-pound of equivalent piloted aircraft—and to performance specifications more exacting than most.

The dollar-and-cents payoff of Martin Systems Engineering is one of the most challenging stories in the aircraft industry today.

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to utilize the remaining fifty per cent of its effort on smaller government contracts and industrially sponsored work which normally involve only one type of research. The industrial work remains a very small percentage of total effort."

• **Douglas Aircraft Company, Inc. . . .**The RB-66A reconnaissance bomber made its first flight on June 28, when it took off from Douglas' Long Beach Division and landed at Edwards AFB, Calif. This USAF sweptwing bomber is powered by two Allison YJ71-A-9 turbojet engines. . . . During its delivery flight to the Navy on June 5, the first production model of the F4D Skyray jet interceptor exceeded Mach 1.0 in level flight. A Navy-Douglas announcement stated that the F4D Skyray is the first Navy plane capable of supersonic combat performance in level flight. The Skyray is powered by a Pratt & Whitney J-57 turbojet engine with afterburner.

• **Eastern Air Lines, Inc. . . .**M. M. (Jack) Frost, formerly Vice-President—Traffic and Sales, is now Executive Assistant to E. V. Rickenbacker, Chairman of the Board, Eastern. Replacing Mr. Frost as Vice-President—Traffic and Sales is William L. Morrisette, Jr., who was the Miami Traffic and Sales Manager.

• **Edo Corporation. . .**The company's Model 2000 floats, with a displacement of 2,000 lbs., have been approved for use with Piper Aircraft Corporation's Tri-Pacer. The gross weight of the Piper Model PA-22 Tri-Pacer as a seaplane is 1,850 lbs.

• **Fairchild Camera and Instrument Corporation. . .**John M. Case has been named Executive Vice-President of the Corporation. He was formerly Vice-President of Marketing.

The Johns-Manville Research Center at Manville, N.J., provides the largest research facilities in the world devoted to building materials, insulations, and allied industrial products. The Administration Building, shown in this photograph, is one of five major buildings that compose the Center. Adjoining the rear of the Administration Building's east and west wings are two Product Development Buildings. The Friction Materials Laboratory, recently opened by Johns-Manville Corporation, is located in Product Development Building #2. Further information on this new Friction Materials Laboratory may be found in the Johns-Manville Sales Corporation item below.

• **Fairchild Engine and Airplane Corporation, Fairchild Aircraft Division. . .** It was announced on June 18 that the corporation is planning to make the St. Augustine, Fla., Municipal Airport a site for "projected operations" of the Aircraft Division. The schedule for facility operation is being announced upon the completion of legal arrangements.

• **Fletcher Aviation Corporation. . .**A new agricultural airplane, the Fletcher FU-24, was scheduled to make its first flight about mid-July. The FU-24, powered by a Continental 225-hp. engine, is an all-metal low-wing aircraft. It has a maximum gross weight of approximately 3,500 lbs. and is capable of carrying a 1,200-lb. pay load. Specifications call for the plane's taking off fully loaded from a 600-ft. unimproved airport. The FU-24 prototype is being shipped to New Zealand immediately after CAA type certification.

• **Flight Refueling, Inc. . . .**The new plant located on a 16-acre plot adjacent to the Friendship International Airport, Baltimore, Md., is now in full operation. The transfer of manufacturing facilities from the company's original plant at Danbury, Conn., was completed early this summer. There are three new Flight Refueling buildings: a main 60,000 sq.ft. manufacturing plant that houses administrative and engineering offices and two test laboratories with a total square footage of 8,000. One of these test laboratories is the only one of its kind known to exist for simulating actual flight conditions of a refueling operation. The Baltimore plant is being formally dedicated sometime this month.

• **General Electric Company. . .**A new and improved airplane landing lamp, rated at 600 watts, has been developed by G-E's Lamp Division. Designated as No. 4559, the new lamp is said to provide (1) a longer more uniform service life than that of its predecessor, (2) more stable beam pattern than heretofore, (3) lower maintenance costs, and (4) greater assurance of safety. . . .A new 18-page bulletin entitled "Five Steps to Productive Maintenance" is now available from G-E's Schenectady, N.Y., office. This bulletin, designated GEA-6087, provides detailed information on organizing to meet the demands that automation will make on an electrical maintenance program.

• **Johns-Manville Sales Corporation. . .**A new Friction Materials Laboratory, devoted to research and development of asbestos brake linings and other friction materials, was opened on June 15 by Johns-Manville Corporation. A part of the Johns-Manville Research Center (see photo on this page) located on the banks of the Raritan River at Manville, N.J., the new laboratory "houses the largest and most versatile inertia-type dynamometer ever built for testing the stopping qualities of aircraft, railroad, truck, bus, and industrial-equipment brake materials." This dynamometer, which weighs more than 200 tons, is capable of reproducing a wide range of braking conditions such as would be encountered by the wheels of a giant bomber or commercial air liner landing at 200 m.p.h., by a train moving as fast as 150

The R3Y-2, a multipurpose bow-loader version of the Navy's R3Y-1 Tradewind, is now in production at the Convair-San Diego Division of General Dynamics Corporation. The R3Y-2, referred to as the "Flying LST," can carry 24 tons of cargo—either materiel or personnel—directly to an enemy beach. For an assault operation, the R3Y-2 lands in offshore waters and taxis to the beach. When the hull touches the sand, the bow is opened upward and a ramp is dropped to permit the unloading of cargo directly onto the beach. To pull off the beach, the pilot reverses the propellers and backs away. The R3Y-2 has a door on the aft port side of the hull for normal dock loading of cargo.

RESEARCH KEEPS **B.F.Goodrich** FIRST IN RUBBER

Now flying with the fleet: WORLD'S FIRST HIGH-PRESSURE TUBELESS TIRE!

NAVY COUGAR JETS are now getting safer, high-speed carrier landings and take-offs with the B. F. Goodrich airplane Tubeless Tire—first high-pressure tire of its kind in the world!

This new airplane tire has no tube to go flat—no tube to bunch up or shift during landings and take-offs. Like the famous B. F. Goodrich Tubeless Tire for passenger cars, it has a patented inner liner, part of the tire itself, that eliminates the inner tube!

With the B. F. Goodrich airplane Tubeless Tire, there's no tube to add weight. And instead of tire and tube, there's only one unit to mount. Only one unit to warehouse, too.

The patented inner liner retains air much longer than conventional tubes. Ridges molded on the outside of the tire bead prevent air loss around the rim. On two-piece wheels, a rubber O-ring seal keeps air from escaping through sections.

Designed and developed by B. F. Goodrich, this new high-pressure Tubeless Tire has passed the most severe tests, including a special "bottoming" test specified by the Navy. It showed the tire retained air even when compressed flat to the rim! Then came successful flight tests on the Grumman Cougar. Now Cougars are making operational flights with the tire. B. F. Goodrich is speeding development for use on commercial aircraft as well as military planes.

The new high-pressure airplane Tubeless Tire is still another first in aviation tires from B. F. Goodrich, leader in rubber research and engineering. Other B. F. Goodrich products for aviation include wheels and brakes, Avtrim, De-Icers, heated rubber, inflatable seals, Pressure Sealing Zippers, fuel cells, Rivnuts, hose and other accessories. *The B. F. Goodrich Company, Aeronautical Sales, Akron, Ohio.*

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m.p.h., or by heavy-duty earth-moving machinery with its low-speed and high-torque application. This dynamometer, capable of producing 100,000 ft.lbs. of braking torque and 51,000,000 ft. bs. of kinetic energy, required more than 2 years to build and represents 10 years of research, engineering, and design work by Johns-Manville scientists and engineers. The new Friction Materials Laboratory also contains many other machines developed by the corporation for testing a wide range of friction materials, particularly automotive brake linings and clutch facings. At the same time this new laboratory was opened, an addition to the Johns-Manville plant at Waukegan, Ill., was announced. This addition, which nearly doubles the passenger car and industrial friction material production there, is a part of the $18,500,000 that Johns-Manville plans to spend for expansion and improvement in 1954.

• **Kollsman Instrument Corporation. . .** The development of the Kollsman Sky Compass was recently announced. This compass is said by the company to be the first practical instrument for accurate aerial navigation in high latitudes and to give the true heading of an aircraft by determining the position of the sun when it is below the horizon. . . .The company has announced that it has entered a new field with the manufacture of magnetic recording systems. The Radio Communications Engineering Section is designing and producing Digital Recording Systems in which the recorded information may be permanently stored or the drums erased for re-use. The magnetic drums need no developing or processing for use as permanent records.

• **Lear Incorporated. . .**According to a recent announcement, the results of a series of performance tests run on the No. 1 production Learstar indicate that it is the world's fastest twin-engined transport airplane. It was also pointed out in that announcement that the Learstar is built to CAA-specified air-line standards and that, of all airplanes designed specifically for executive transportation, it is the only one designed for flight qualification under the identical stringent CAA "4b" specifications required of such modern air liners as the DC-7 and Super Constellation. . . . On July 1, a new export distributing firm, Lear International, Inc., became the exclusive export agent for all Lear products, with the exception of certain products in Canada. Lear International, headquartered at 345 Madison Ave., New York, N.Y., absorbed Lear International Export Corporation, former export distributor for Lear products. In addition to the New York offices, the new company has offices at 54 Ave. d'Iena, Paris, France, and at 1001 Connecticut Ave., Washington, D.C.

• **Lockheed Aircraft Corporation. . .**The U.S. Air Force announced on July 7 that the Lockheed XF-104 day fighter made its first flight at Edwards AFB, Calif., in February, 1954. This ship was flown approximately 1 year after the order for the new plane was placed by the Air Force. The XF-104 is powered with a J-65 jet engine, which is manufactured by Curtiss-Wright Corporation and rated at more than 7,220 lbs. of thrust. . . .The Air Force has ordered an undisclosed number of Super Constellations to be used by the Military Air Transport Service as personnel-cargo-evacuation transports. Deliveries of this transport, designated by the Air Force as the C-121C, are scheduled to begin in mid-1955. As a personnel carrier, the C-121C can seat a maximum of 106 in the long-range overwater configuration or can hold 73 litters plus hospital attendants. As a cargo ship, it can carry more than 15 tons across oceans or continents.

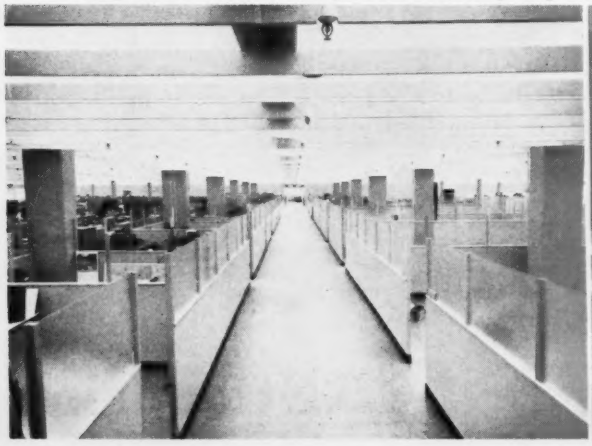
• **The Glenn L. Martin Company. . .**The U.S. Navy accepted delivery of the first production P5M-2 Martin Marlin on June 23. An improved version of the P5M-1 Marlin, the P5M-2 has a high "T" tail and a bow that closely resembles that of a speedboat. The Marlin is powered by Wright 3,450-hp. turbo-compound engines and contains the latest electronic equipment to assist it in its antisubmarine role.

• **Minneapolis-Honeywell Regulator Company. . .**A sensitive robot hand that can function at distances ranging from 1 to 1,000 ft. has been developed primarily for operating remotely located control of reciprocating aircraft or automotive engines during test work. This system, known as electronic remote positioning system, is said by the company to be 100 times more responsive than conventional or hydraulic systems previously used for this function. A typical application of this robot hand is the operation of spark advance or inlet air mixing devices on reciprocating aircraft engines. The system may be modified to permit actual vehicle or aircraft installations so that tests can be conducted during regular use. . . .A new precision switch, designated IHTI and said to be ideal for high-temperature aircraft applications, has been announced by Micro Switch, a division of the company. This unit reportedly has a capacity for switching a substantial electrical load in a temperature range of −50° to +1,000°F. Characteristics of the IHTI are given as follows: operating force, 10 to 20 oz.; pretravel, 0.065 in. max.; differential travel, 0.010 in. max.; and overtravel, 0.125 in. max.

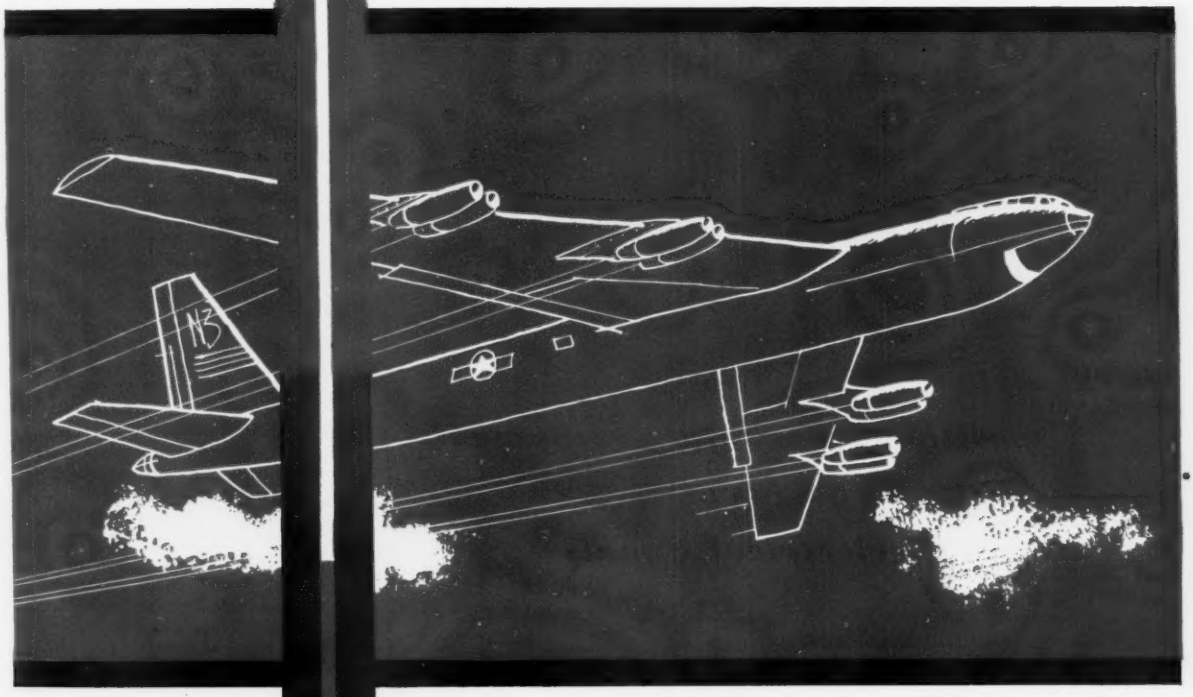
• **Northrop Aircraft, Inc. . . .**According to a company release, an exacting refinement of "upstream" assembly techniques has enabled the company to develop a final assembly line for F-89D Scorpions which measures only 550 ft. and which contains only 11 stations. In terms of the F-89D Scorpion, this upstream assembly method means that every possible component and equipment item is installed in major subassemblies before being sent to final assembly. Once these major assemblies reach final assembly, they are simply lifted into position by overhead conveyors or by simple adjustable-height dollies and bolted to the fuselage.

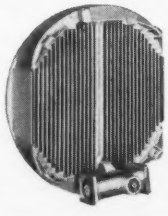
• **Pan American World Airways, Inc. . . .** The recent delivery of the forty-fifth Douglas Super-6 Clipper completed a $58,000,000 program that the company says has made it the largest operator of

A $2,000,000 Aircraft Engineering Center, featuring a roof-top heliport for the quick transportation of engineers, was dedicated on July 3 at the El Segundo Division of Douglas Aircraft Company, Inc. Constructed of steel and concrete, this two-story air-conditioned building houses El Segundo's Engineering Department headed by Chief Engineer Edward H. Heinemann, FIAS. Its two engineering rooms have the world's largest open-area translucent ceiling (2 acres) utilizing 5 miles of fluorescent tubes giving a total of 3,500°K. of light. The corrugated luminous ceiling, Douglas says, provides at each engineering drafting board a shadowless light of at least 90 foot-candles. This ceiling lighting can be seen in the photograph at the left which shows the main aisle on the Center's second floor. The picture at the right shows Mr. Heinemann addressing the guests and members of the press at the formal opening of the building.



HARRISON KEEPS IT COOL UNDER FIRE





Beyond the sound barrier there's another barrier—*heat!* Keeping modern engine bearings cool under fiery jet temperatures—*that's Harrison's job!* Keeping passenger compartments and cockpits comfortable—*that's Harrison's job*! For Harrison manufactures oil coolers and cabin coolers for many of today's modern aircraft. And Harrison coolers are engineered for every job. They're dependable, durable . . . designed to save space, weight . . . money, too! Design of this aircraft cooling equipment is another example of Harrison leadership in temperature control. If you have a cooling problem, look to Harrison for the answer!

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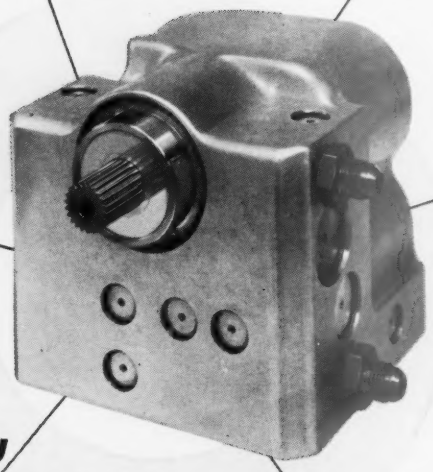
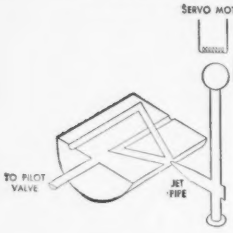


accurately positions heavy duty equipment by means of minute electrical signals

This Electro-Hydraulic Servo System is ideally suited for industrial controls to maintain flows, ratios, levels, pressures, speeds and for machine tool positioning. It is a 5¼" cube self-contained unit and weighs but 12 pounds.



The Kearfott Electro Jet utilized the Askania jet pipe principle, characterized by high frequency response, rugged construction and highly accurate shaft positioning. Rated output is 200 inch pounds torque through ±60 degrees. Maximum torque rating is 333 inch pounds. Frequency response is flat (within 3 db) up to 25 cycles. Resolution of the output piston positions is one part in 500 or better.

Write today for full information about the Kearfott Electro Jet. It may help in the solution of your control problem.

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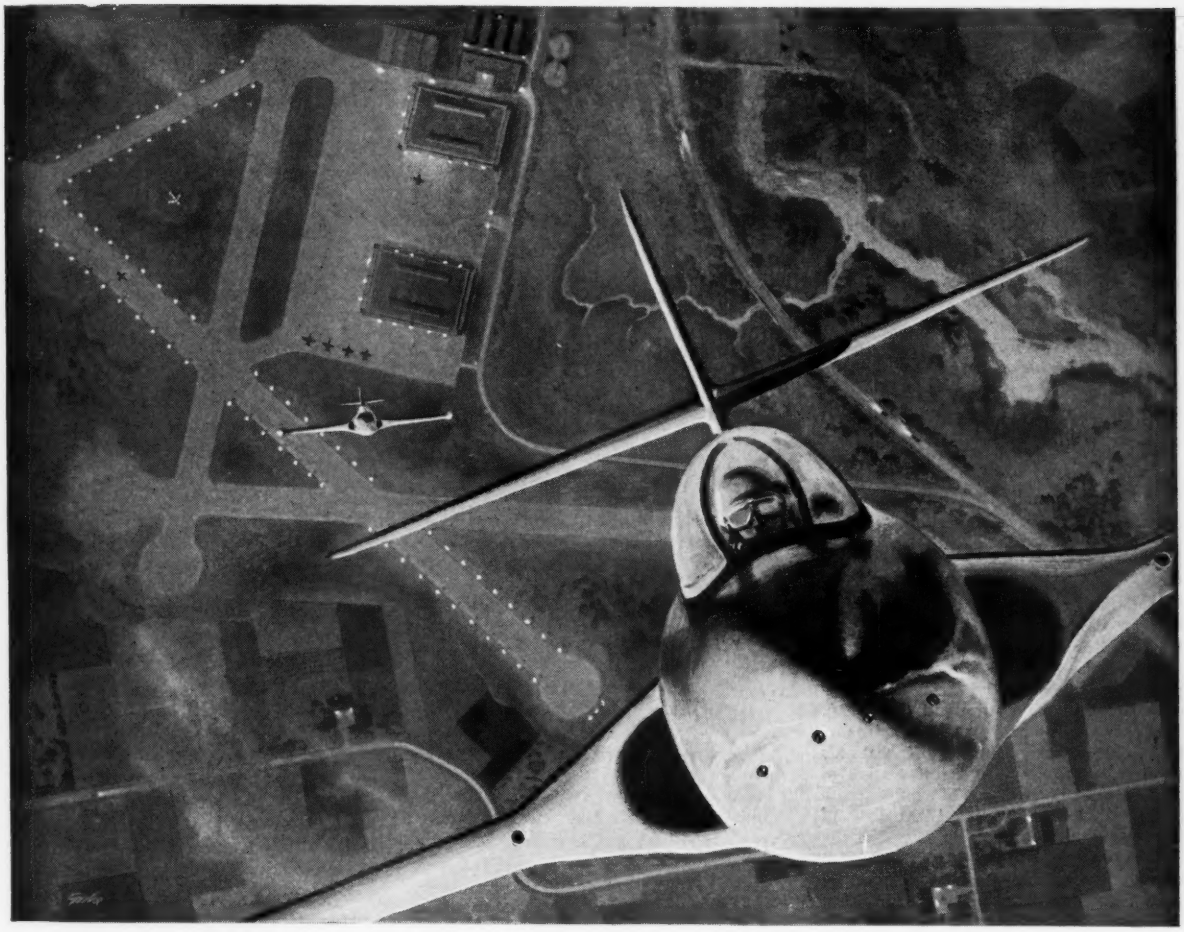
such planes in the world. The first Super-6 Clipper was delivered on February 26, 1952. Pan American has also received the last of three DC-6A air freighters for transatlantic all-cargo service. The air line's fleet will be augmented next year when seven DC-7B's are delivered between May and August. . . . A new travel book, "New Horizons," has been compiled by Pan American from information supplied by the air line's staff in 84 countries on six continents. Contained in its 576 pages are 16,201 facts that "a traveler needs to know." These include answers to such questions as: will the electric razor work on the local voltage, how quick is the laundry service, how much does one tip, and what should one wear, do, eat, buy, and see. This pocket-sized book costs $1.00 and is available at any Pan American office or by writing to Pan American World Airways, P.O. Box 1111, New York 17, N.Y. Published by Simon & Schuster, it may also be obtained at book stores at the same price. . . .Henry H. Berke was elected Vice-President—Services of Supply of Pan American. He had been Assistant Vice-President—Services of Supply since 1945. . . .Everett M. Goulard has been elected Assistant Vice-President—Industrial Relations of Pan American. Mr. Goulard joined Pan American in 1948 as a member of the Industrial Relations Department.

• **Pan American World Airways, Inc., and American Airlines, Inc. . . .**American has joined Pan American's Pay Later Plan, thus extending the benefits of this plan to domestic points in conjunction with overseas transportation on Pan American. Under the terms of this Pay Later Plan, a down payment of 10 per cent is made, and the balance is paid over a period of months. The plan covers not only the air travel but also hotel accommodations, sightseeing tours, and overland transportation arranged for in the United States. Prearranged tours may also be financed under this plan. American's participation in this plan makes it available from any domestic point served by American to any point in the world flown by Pan American.

• **Piasecki Helicopter Corporation. . .**The three hundred and thirty ninth and last Piasecki HUP helicopter was delivered to the Navy on July 1 and was flown to Helicopter Squadron HU-2, U.S. Naval Air Station, Lakehurst, N.J. The initial development contract for three XHJP-1 helicopters was awarded to Piasecki in February, 1946. The first production contracts for the HUP-1 were received in August of 1949, with the first production aircraft being delivered to Helicopter Squadron HU-2 in January of 1951.

• **Reaction Motors, Inc. . . .**The Navy Department announced on July 1 two significant developments in the helicopter field, these involving Rotor-Craft Corporation's RH-1 and Kellett Aircraft Corporation's KH-15. Both of these Navy research projects are concerned with separate phases of helicopter development. In the case of the RH-1, it is the first experimental helicopter to utilize rocket engines as the sole power source and has been used to explore the field of rocket propulsion for helicopters. The Navy



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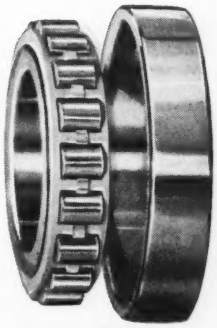

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has described the purpose of the KH-15 program as being the investigation and flight testing of a new gyro-stabilizing system. Both of these helicopters, the RH-1 and KH-15, are powered by small liquid-propellant rocket engines developed and supplied by Reaction Motors. These rocket engines produce a thrust of approximately 16 lbs. and are installed at the tip of each rotor blade. Each engine weighs in the order of 1 lb. and can be held in the palm of the hand. In both the RH-1 and KH-15, a liquid rocket fuel is fed to each rocket engine from a single fuel tank by fuel lines running through the length of each rotor blade. Propellant feed is achieved by high-pressure inert gases. . . . Raymond W. Young, President and General Manager of Reaction Motors, recently announced the names of new officers elected by the corporation's Board of Directors. These newly elected officers are Henry H. Michaels, Jr., Executive Vice-President and Assistant General Manager; James W. Fay, Jr., Treasurer and Assistant Secretary; and Robert M. Lawrence, Assistant Secretary. Alexander L. Keyes continues as Secretary and General Counsel.

• **Ryan Aeronautical Company. . .**The U.S. Air Force has ordered an undisclosed number of Ryan Firebee pilotless jet planes. U.S. Navy and Army Ordnance orders are currently in production at Ryan. The USAF Firebees will be equipped with Continental Motors Corporation's J-69 jet engine, the American version of the French Turbomeca Marbore which generates approximately 1,000 lbs. of thrust. USN and USA Firebees use the J-44 jet engine, manufactured by the Fairchild Engine Division of Fairchild Engine and Airplane Corporation. The Firebee project was started 4 years ago as a joint development of the Army, Navy, and Air Force. . . .An additional company-financed test cell is now being constructed for the purpose of maintaining Ryan's position in jet-aircraft and jet-engine components fields. This cell reportedly will be the largest and most advanced type in the area.

• **Sperry Gyroscope Company, Division of The Sperry Corporation. . .**Vice-Presidents Carl A. Frische, AFIAS, and E. U. DaParma have been given new and broader responsibilites. Dr. Frische, who was named Vice-President for Engineering in 1945, has been appointed Vice-President for Operations and will have under his direction the activities of both the Engineering and Manufacturing divisions. Mr. DaParma, who became Vice-President for Manufacturing in 1952, is now Vice-President for Special Plans and Coordination with other plants within the Sperry Corporation. These include the Marine Division, Electronic Tube Division, Sperry Farragut Corporation, Wright Machinery Company, and the Sperry companies in Canada.

• **Standard Oil Company (Indiana). . .** Under the terms of a USAF-Standard Oil Company contract, Standard Oil is to build and operate for the ARDC's Wright Air Development Center a pilot plant for certain types of solid propellants for rockets. This plant is to be erected on a 156-acre tract at the northwest corner of Freeman Field, Seymour, Ind. Construction on this plant, to be supervised by Standard Oil and paid for by the Air Force, is to begin in late summer or early fall. Two buildings now existing on the site are being rehabilitated, and an administration building and two other operating buildings are to be constructed. All of the buildings will be single-story structures. Techniques to be used in this pilot plant will be those developed since 1951 in Standard Oil's research laboratories at Whiting, Ind.

• **United Air Lines, Inc. . . .**A plotting grid map has been adopted by United as an effective way of keeping pilots posted on thunderstorm movements. This map, which covers United's New York-Salt Lake City segments, is divided into grids of 1° latitude and longitude. The grids are identified by the two-letter sequence employed by the Air Force. To help the pilot keep track of thunderstorm movements, thunderstorm grid messages (TGM's) are broadcast blind by United every hour on the hour. The pilot marks the grids named on his map for reference in planning detours. These maps, published by Jeppeson and Company in Denver, are designed for discard after each use.

• **Western Gear Works. . .**A new electric motor-driven rescue or cargo hoist developed for aircraft use has been announced. This hoist is a complete package including electric motor with magnetic brake, gear reduction, cable drum, and level winding mechanism. It is capable of raising or lowering a normal load of 800 lbs. at a rate of 50 ft. per min. and has a maximum operating load of 1,200 lbs. Maximum static load is 3,000 lbs. The hoist has been fully tested for use under environmental conditions encountered in aircraft applications up to 20,000 ft. in altitude and from −65° to +160°F. Total weight of the hoist assembly, without cable, is approximately 25 lbs. The unit can be arranged for duty cycles up to and including continuous duty.

• **Westinghouse Electric Corporation. . .** The Aviation Gas Turbine Division has created a new Sales and Service Department. Romus Soucek, MIAS, has been appointed Sales Manager of the new department, with Raymond B. Rogers as Assistant Sales Manager.

IAS Sections

Baltimore Section

The following officers of the Baltimore Section have been elected for the year, 1954–1955: Chairman, Herman Pusin; Vice-Chairman, Donald J. Povejsil; Secretary, Raymond D. Blakeslee; and Treasurer, Raymond H. Fields. The Area Councilor is Joel M. Jacobson. The Advisory Board is composed of George F. Towner; Herman C. Wieben; Brig. Gen. L. I. Davis, USAF; Paul A. Piper; Albert J. Kullas; Charles H. Niles; Joseph P. Paine; and Joseph F. Maloney.

Hampton Roads Section

John E. Duberg
Recording Secretary

On May 5, the Hampton Roads Section of the IAS held its annual dinner meeting. More than 60 members and guests assembled for the dinner and the social hour preceding the dinner.

The speaker for the evening was Randolph Hawthorne, Editor of *Aviation Age* magazine. He was introduced by Dr. John E. Duberg, Chief of the Structures Research Division, Langley Aeronautical Laboratory, NACA.

Mr. Hawthorne spoke on the development of Russian air power since World War II and traced the influence of the Russian and German designs through the various Russian aircraft known to be operating. Some mention was made of the Russian engine development and of the production centers that are known to exist.

▶ On June 12, Capt. Harry E. Sears, Commander of the aircraft carrier, U.S.S. "Coral Sea," invited the Hampton Roads Section of the IAS to visit his ship anchored in the Hampton Roads; 72 members and guests accepted his invitation. (See photo, page 102).

On board the "Coral Sea," the visitors were divided into about 15 groups. Each group was assigned to an officer and was taken on a tour of the ship which lasted more than 2 hours. Stops were made in the storage bays, flight elevators, and pilots' ready room, as well as in those parts of the ship concerned with the carrier's operation—the bridge, engine rooms, and information control center where all radar information is received and distributed.

On the flight deck, the catapult launching techniques were described, and the arresting gear was shown. In addition, a helicopter was displayed, and the role of the helicopter in pilot rescue work was described. The operation of the 5-in. antiaircraft guns was also demonstrated.

The tour was ended with the showing of two motion pictures depicting the role of the aircraft carrier. After luncheon, which was served in the Officers' Mess, the visitors returned to the flight deck from which they watched the "Coral Sea" return to her dock.

New York Section

T. F. Hammen, Jr., *Secretary*

A well-attended and interesting dinner meeting on the subject of the "De-

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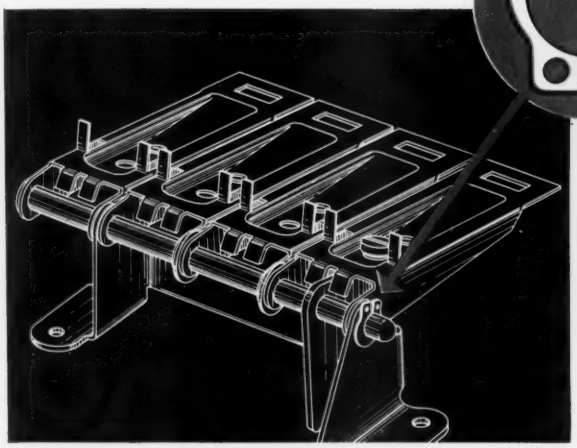

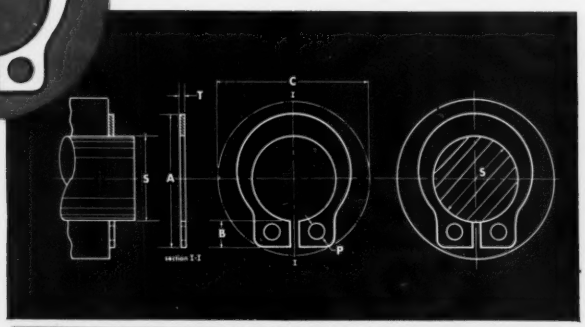

Ring # 5555		5555-12	5555-13½	5555-18	5555-25	5555-31	5555-37
SHAFT DIAMETER	Fract. Equiv. S	1/8"	—	3/16"	1/4"	5/16"	3/8"
	Dec. Equiv. S	.125	.136	.187	.250	.312	.375
	TOL.	±.002	±.002	±.002	±.002	±.003	±.003
RING DIMENSIONS	Thickness T	.025	.025	.035	.035	.042	.042
	TOL.	±.0015	±.0015	±.002	±.002	±.002	±.002
	Length A	.268	.285	.364	.437	.553	.626
	Lug B	.078	.078	.097	.097	.141	.141
	Hole P	.042	.042	.042	.042	.078	.078
	Min. Ring Clear C	.33	.34	.44	.50	.67	.73
Approx. Ultim. Thrust Load (Lbs)		20	20	25	35	50	60

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The Grip Ring can be installed tightly against a machine part in order to take up end-play. The basic Truarc design principle assuring complete circularity around periphery of the shaft and the ring's unusually large radial width combine to exert considerable frictional hold against axial displacement. The ring can be used again and again.

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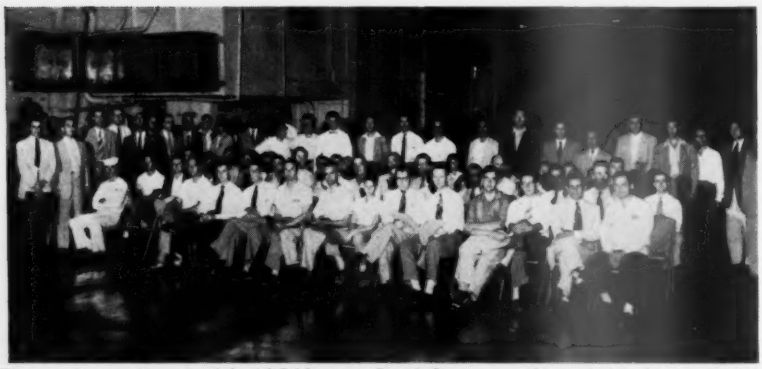


The members and guests of the IAS Hampton Roads Section are shown during their inspection trip of the U.S.S. "Coral Sea" on June 12.

velopment and Achievement of the Vickers Viscount" was held on May 27 at Kohler's Swiss Chalet in Rochelle Park, N.J. This meeting was chairmanned by Christopher Clarkson, U.S. Representative, Vickers-Armstrongs, Ltd. The speaker was Allen Greenwood, Service Manager, Vickers-Armstrongs, Ltd. A summary of his illustrated presentation is given below.

Mr. Greenwood started his discussion of the Vickers Viscount, a civil aircraft powered by four Rolls-Royce Dart propeller-turbine engines, with a statement to the effect that during the war the design and construction of civil aircraft virtually ceased. When victory in Europe seemed certain, Lord Brabazon was charged with the duty of defining the types of aircraft which Britain should produce during the postwar years in an attempt to regain some of the markets that were being lost to American competitors. The Viscount is one of a series of five main types recommended and expected to be available for service by the middle 1950's.

An interim type, the Vickers Viking, was developed to provide an aircraft immediately at the war's end in the hope of capturing some of the revenue from the intercontinental capital routes. This airplane first flew on June 22, 1945, and by 1947 was in service with the British European Airways Corporation, carrying passengers to the main capitals of Europe. During the next 3 years, 163 Vikings were built for air lines in Great Britain and other countries and for the RAF.

It was decided the Viking's successor would commence as a 32-seater with a 42,500-lb. gross weight and a safe range of 1,200 nautical miles. It should be capable of cruising at not less than 300 m.p.h. at an altitude that would be above the normal bad-weather heights, yet not so high that on the shorter routes the flight plan would consist of a climb followed by an immediate descent. Safety was to be of paramount importance, and for this reason four engines would be used. The cruising altitude was fixed at 25,000 to 30,000 ft. by the conditions already described. Design work commenced in mid-1946.

The solution of the engine problem was not simple. Four small engines were required which would develop at least 1,000 b.hp. each, at 25,000 ft., and which would give safe and reliable service. The available engines fell into three categories: first, small reciprocating radials, such as the Bristol Taurus; second, turbojets, such as the Rolls-Royce Nene or Derwent; and last, one of the new and untried turboprops, such as the Napier Naiad, the Armstrong-Siddeley Mamba, and the Rolls-Royce Dart.

The radials were immediately discarded, because their power curves fall off sharply with altitude, and also because they would certainly be obsolete within the anticipated life of the new airplane. The turbojets were, on the whole, too large, and they did not give their best performance below aircraft speeds of 450 m.p.h. or altitudes of 40,000 ft. Two Nenes were, however, fitted into a Viking, and a great deal of test work was done. This Viking, incidentally, broke the London-Paris speed record in July, 1948, with an average speed of 384 m.p.h. and was the first civil jet airplane in the world to fly, this being nearly a year before the Comet. The engines finally selected were the Rolls-Royce Dart turboprops, having a power output of 1,000 s.hp. augmented by 200-lb. thrust at a weight of about 925 lbs. Basically, the power plant consists of a Rotol 10-ft.-diameter fully feathering propeller, a 10:1 reduction gear, a two-stage centrifugal compressor, seven flame tubes, and a two-stage turbine.

The question of engine reliability and handling still remained unanswered; so the ever faithful Wellington was pressed into service. During 1947, two prototype Dart engines were fitted into a suitably modified Wellington air frame, and a considerable amount of test flying was done to check engine powers, fuel consumptions, and general handling characteristics. The results of these tests were extremely promising, although much of the work had, of necessity, to be done below the most favorable altitudes. It was in this airplane that the great reduction in noise and almost complete lack of vibration from turbine engines became a reality. This was in large part due to the complete absence of reciprocating parts. In spite of the inadequately heated fuselage and the wearing of oxygen equipment, the pleasure of turbine-engine flying became apparent.

Two prototypes were constructed—one having Dart engines and the second, with an eye to the future, having two Rolls-Royce Tay turbojets. Both of these aircraft were 74 ft. long, had a wing span of 88 ft., and were 27 ft. high. On July 16, 1948, the Dart-engined prototype was successfully flown. It thus became the first turboprop civil airplane in the world to be air-borne. This prototype has since flown under all sorts of conditions in most parts of the world.

In the first prototype, the Viscount 630, the normal fuel—aviation kerosene—is carried in crashproof bags in the outer wing panels. Overload fuel cells are installed in the inner panels giving a total capacity of 1,200 imperial gal. The tricycle landing gear, brakes, and nose-wheel steering gear are controlled hydraulically, the oil pressure of 2,000 lbs. per sq.in. being obtained from engine-driven pumps or, in the case of the nose wheel, from an electro-hydraulic unit.

After the first flight of the prototype in July, 1948, there commenced a strenuous flight-test program designed to cover engine and air-frame performance and handling with a view to obtaining a full passenger-carrying British Certificate of Airworthiness. These tests included successful flights in severe ice-forming conditions. In the autumn of 1949, the Viscount was flown to Khartoum—where the temperature was 115° F.—for tests under tropical conditions, and then to Nairobi for take-off trials from the high-altitude field that has an elevation of 5,300 ft. These tests showed that the take-off power of a turbine engine falls off considerably with increase in ground temperatures and that, if the Viscount was destined for a world-wide market, this feature had to be overcome. After an exhaustive series of engine tests, it was found that this power would be completely restored by injecting a 60/40 mixture of water/methanol into the engine at the compressor entry vanes. This mixture reduces the flame temperature sufficiently to overcome the disadvantage of the hot tropical intake air.

In July of 1950, the British Air Registration Board granted a full Certificate of Airworthiness. Following this,

the Viscount was put into regular passenger service for an experimental period.

It had been decided that the economic potential of the Viscount could be considerably improved if it could carry 40 to 50 passengers over a range of 1,600 miles. A third prototype, known as the Viscount 700, was built having a length of 81 ft. and a span of 94 ft. with seating provisions for 40, 48, or 53 passengers. Engine power of the Darts had been increased to 1,400 s.hp. with an augmented thrust of 365 lbs. This airplane cruised satisfactorily at 320 m.p.h. at 25,000 ft. with a fuel consumption of slightly better than 1.2 miles per gal.

The time had now come to prepare firm specifications by which Viscounts could be offered for sale throughout the world. The first of these was based on the "700" prototype, with a gross weight of 50,000 lbs. and a fuel-system capacity of 1,720 imperial gal. New additions included additional freight holds below the cabin floor to which access could be gained through doors fitted in the underside of the fuselage.

The second specification included an enlarged fuel system, carrying 1,950 imperial gal., and a gross weight of 58,500 lbs. These 58,500-lb. aircraft are all stressed for future development to better than 60,000 lbs.

The third specification was based on a 58,500-lb. airplane. This aircraft, however, was equipped with external wing "slipper" tanks, carrying an additional 145 imperial gals. per side.

Aircraft have been built and delivered to the first two specifications, and flight tests on the first of the slipper-tank aircraft, built for an Australian air line, are due to commence shortly.

The prototype Viscount 700 was subsequently flown to Canada via Iceland, Greenland, and Labrador and completed 800 hours of demonstration flying during which temperatures of −26°F. were frequently encountered causing the aircraft little embarrassment.

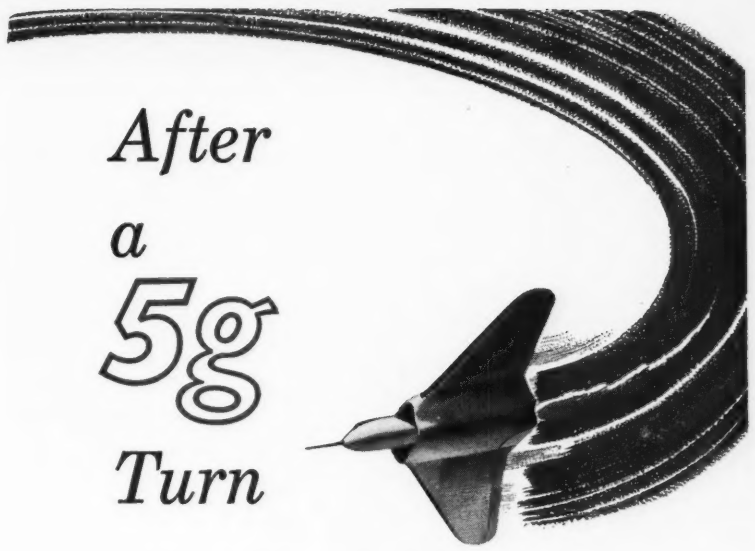
Increases in engine power and reduction in specific fuel consumption, already announced by Rolls-Royce, will permit raising the gross weight and improving the performance of the aircraft.

Mr. Greenwood's lecture was excellently illustrated with slides.

San Diego Section

H. C. Matteson
Corresponding Secretary

"Some Operational Problems of Turbine Engines" was the title of a talk given before the San Diego Section on June 29 by Abe Silverstein, Associate Director of the NACA Lewis Flight Propulsion Laboratory. Mr. Silverstein's talk was based on his formal paper bearing the same title presented



IS THE DATA VALID?

The moment an oscillograph is taken out of the laboratory for aircraft flight testing, vehicle road tests, or any application where vibration and dynamic g forces are present, the "balance" of its galvanometers—the measure of their response to gravitational force—becomes all-important. An unbalanced galvanometer can cause deflections—under only moderate g-loadings—large enough to distort a data trace and make accurate record interpretation impossible. It can show deflections even when no data signal is present.

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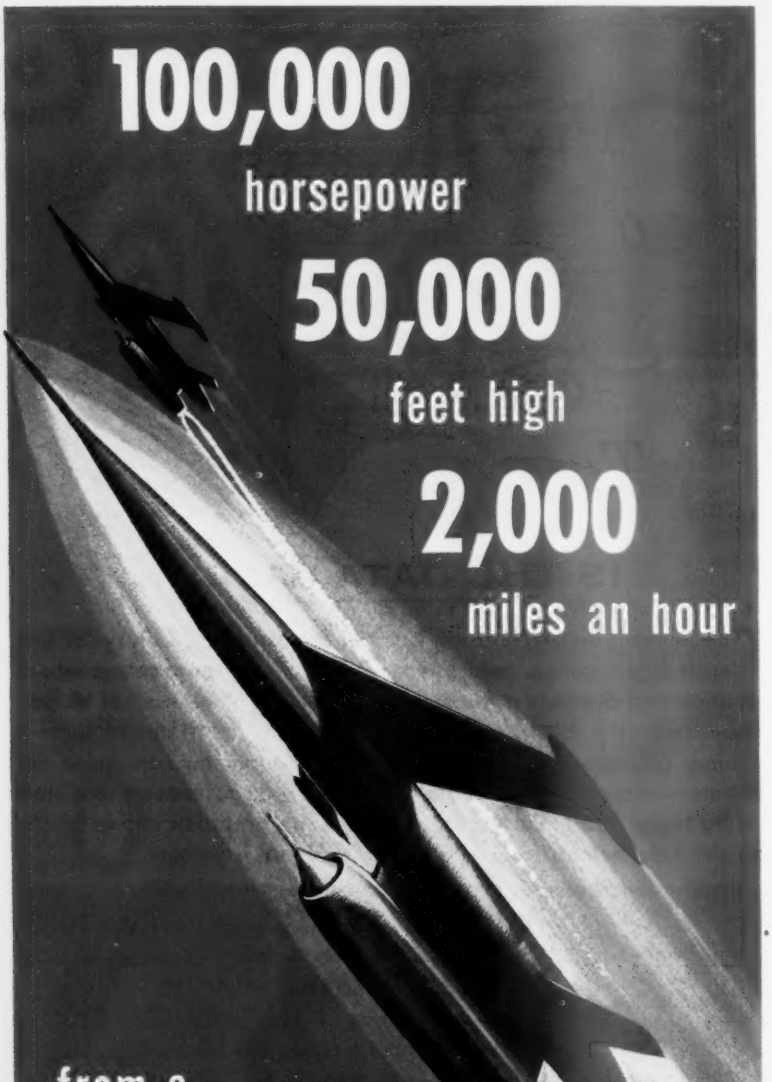


at the Annual Summer meeting in Los Angeles.

The speaker reviewed some of the more significant operational problems of turbine power-plant installations, particularly as they are affected by extending the speed range to Mach Numbers well in excess of 1.0. Compressor stall, inlet and exit matching, and duct buzz problems were discussed. The effects of extreme speed and altitude on fuel-system design requirements were outlined. Some problems associated with reverse-thrust installations were reviewed.

In closing, Mr. Silverstein emphasized the necessity for careful integration of power-plant design detail at an early stage in the overall aircraft design development in order to assure satisfactory operational characteristics and good efficiency from the turbine installation.

Approximately 80 members and guests were in attendance. Coffee and doughnuts were served at the close of the meeting.

Washington Section

T. C. Muse, *Secretary*

On June 16, 65 members and guests of the Washington Section made a trip by bus to the Naval Air Station, Patuxent River, Md., for the last meeting of the 1953–1954 season.

The group was welcomed to the Station by Rear Adm. C. H. Duerfeldt, Commander of the Test Center. A lecture on "Aircraft Electrical Interference Elimination," by J. F. Plunkert, and another one on "Aircraft Antenna Location Problems," by R. L. Hensel, were then given to the group. Both of these lectures were concerned primarily with the problems encountered in the development of electronic systems with air-borne early-warning aircraft.

The principal facility that the Navy has for carrying out this work is the shielded hangar. This hangar is shielded internally by galvanized wire screen having 8 mesh to the inch. This screen covers walls and ceiling and is under the floor. All portions are connected to produce a complete unbroken shield. Doors and other entrances are so conceived that when they are closed they too form an integral part of the shielding. In this facility, the electronic equipment can be tested with very satisfactory level of background noise, a condition completely impossible without the hangar. With this facility, the noise levels of various components can be isolated.

After inspection of the shielded hangar, the group was taken to the armament test area where a static firing demonstration of the FJ-2 armament

was made. Firing tests on an AD-4 rigged to measure firing dispersal were also witnessed. Static demonstration and explanation of various external stores completed the armament portion of the demonstration.

After lunch at the Officers Club, the group visited the steam catapult area. The steam catapult is a recent development that is expected to solve some of the more difficult problems associated with catapulting of aircraft. By virtue of using steam, it is able to reduce the logistic problem associated with present powder catapults and at the same time has the advantage of attaining higher capacities. The group was much impressed by the multitude of piping, steam boilers, accumulators, and other equipment necessary for operation of the catapult. Needless to say, some of this steam equipment is superfluous on shipboard but is necessary for a shore installation. The steam catapult, not completed at the time of this visit, is expected to be in operation in the near future.

A hydraulic catapult, however, is in operation, and catapult launchings were made of a Chance Vought F7U-3, a Grumman F9F-6 and F9F-8 and a Douglas AD-4. In spite of a relatively high cross-wind, the aircraft were launched and retrieved in a routine manner. While it appeared to be a routine operation for the Navy, it was certainly a spectacular demonstration for the visitors—especially so when it was announced that the catapulting and retrieving of the F9F-8 was the first ever made of this aircraft.

The tour of the flight-test area was completed with an examination of the hydroski Grumman JRF-5 amphibian and a snowski-equipped Lockheed P2V. Other flight-test aircraft, such as the Grumman F2F-1, the Grumman F9F-8, the Chance Vought F7U-3, the Douglas AD-6, the North American T-28B, etc., were examined on the flight line.

After the technical inspection, the group held a short business meeting that culminated in the installation of the new officers of the 1954–1955 period. Those installed are: Chairman, Brig. Gen. B. S. Kelsey, USAF; Vice-Chairman, Herbert L. Goda; Secretary, R. Fabian Goranson; and Treasurer, R. Douglas Smith.

Although an overcast sky caused certain of the flight demonstrations, namely air-to-ground rocketry, to be cancelled, it did keep the temperature within a comfortable range during the day. The trip, itself, was excellent and is to be recommended highly for future years. This Section is grateful to Admiral Duerfeldt and his staff for the fine demonstration of Naval aeronautical activity.

The IAS Student Branch at California State Polytechnic College held its Annual Spring Banquet on June 5. Shown during this banquet are *(left to right)*: Jack Gresham, Incoming Student Chairman; Robert Garrison, Outgoing Student Chairman; Ernest G. Stout, Convair; Lester W. Gustafson, Cal Poly; and E. W. Robischon, IAS.

Student Branches

California State Polytechnic College

Jack Gresham, *Incoming Chairman*

The Student Branch of the Institute of the Aeronautical Sciences at California State Polytechnic College held its Annual Spring Banquet on Saturday, June 5. Forty-five members and guests were present.

Honored guests were Ernest G. Stout, Staff Engineer, Convair Division of General Dynamics Corporation, recipient of The Sylvanus Albert Reed Award for 1953 and principal speaker for the evening; E. W. Robischon, IAS Western Region Manager; and Lester W. Gustafson, Head of the Aeronautics Department at Cal Poly.

Immediately following the dinner, Chairman Robert Garrison introduced Mr. Robischon who congratulated the group on its outstanding job in helping to organize the Annual Student Conference in Los Angeles.

Mr. Gustafson then presented this year's Student Branch Scholastic Award and Student Branch Lecture Award to Daniel Hickey and William Chabot, respectively.

Mr. Stout delivered a talk entitled "The Development of High-Speed Water-Based Aircraft." In discussing the problems involved, Mr. Stout made use of many interesting slides. These slides outlined the history of water-based aircraft from the early attempts of Glenn Curtiss to the highly successful hydroski-equipped Sea Dart, built by Convair. Mr. Stout told the group about the hydrodynamic problems encountered in designing water-based aircraft with high-speed characteristics. He described Convair's use of dynamically similar models to save engineering hours and taxpayers' money in solving these hydrodynamic problems.

The meeting was closed by a presentation of the officers elected to head the IAS group next year. These are: Chairman, Jack Gresham; Vice-Chairman, Robert Ahrens; Secretary, Gerald Moulin; Treasurer, Ted Johnson; and Corresponding Secretary, Eugene Robinson.

Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Ballantyne, A. M., Ph.D., Secretary, Royal Aeronautical Society.

Bruce, Douglas M., B.Sc. in M.E., Struct. Group Engineer, Bell Aircraft Corp.

Covington, G. C., B.S.M.E., V-P, Airplane Engrg., McDonnell Aircraft Corp.

Transferred to Associate Fellow Grade

Berry, Frederic A., M.S., Capt., USN; Officer in Charge, Project AROWA, NAS (Norfolk), BuAer, Dept. of the Navy; Officer in Charge, Comdr., Eastern Sea Frontier, New York, U.S. Fleet Weather Central.

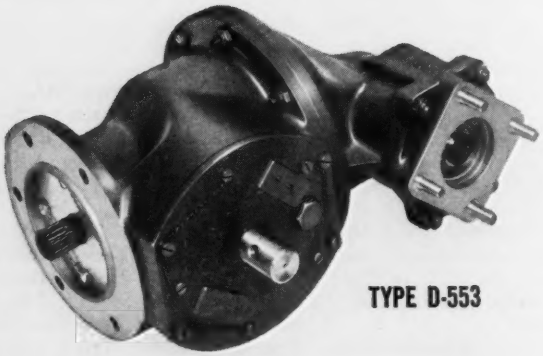
MANY PURPOSE

ROTARY ACTUATORS

EEMCO has developed many types of rotary actuators for leading air frame manufacturers for use in the newest jet aircraft and commercial airliners. The models shown here are typical of the many varied designs that have been produced for a wide variety of uses. This manufacturing experience is evidence that **EEMCO** is staffed and equipped to develop any type of actuator, rotary or linear, to your exact specifications designed to draw power from any source. In many cases an existing **EEMCO** model can be adapted to your specifications which will speed delivery time considerably.

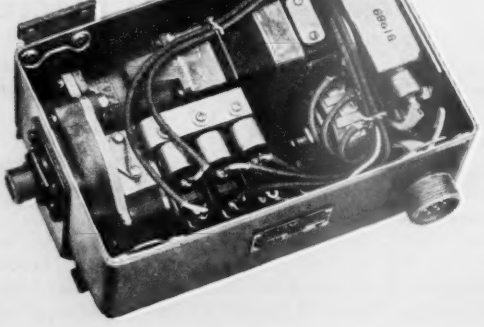
TYPE C-824

Type C-824 EEMCO reversible actuator was developed for opening and closing an aircraft canopy. It develops 150 inch-pounds of torque at 81 R.P.M. in intermittent duty, utilizing 26 volts DC. Gear ratio is 141 to 1. Weight is 6¼ lbs., including radio noise filter.



TYPE D-553

Type D-553 Vericam actuator, developed for use on Lockheed P2V., is hydraulically operated. Designed for continuous duty reversible operation, it is equipped with multiple disc torque limiter and directional torque limiter on the manual operation shaft. Normal output load at 240 R.P.M. is 250 inch-pounds. Torque limiter setting is 325 inch-pounds. Weight is 12 lbs., 5 oz.



FLEXIBLE UNIVERSAL POWER PACKAGE TYPE D-471

Type D-471 EEMCO rotary power package combines in one small container: motor, radio noise filter, magnetic clutch and brake, main reduction gear and auxiliary gears for driving adjustable limit switches, light switches and position indicator. It has a wide variety of possible adaptations utilizing flexible shafting to drive small rotary or linear actuators singly or in multiples. Dimensions are only 7⅛"x4⅛" x 2¾". Weight is only 3⅜ lbs. Specifications may be varied to suit special requirements.

TYPE D-357

Type D-357 EEMCO-designed canopy actuator develops 50 inch-pounds at 280 R.P.M. operating on 28 volts DC in intermittent duty. Gear ratio is 40 to 1. Unit includes magnetic clutch and brake and radio noise filter. Stall torque is 300 inch-pounds maximum. Weight is 4¾ lbs.

Type D-374 EEMCO camera door actuator has dual output shafts with 175° rotation at 1 second maximum. It is equipped with adjustable limit switches, radio noise filter, magnetic clutch and brake. Output is 280 inch-pounds of torque on each shaft. Gear ratio is 441 to 1. Weight is 8¾ lbs.

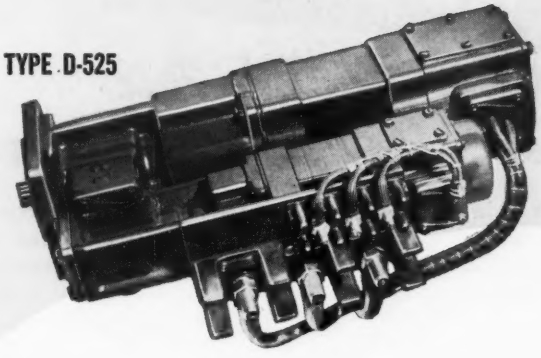
TYPE D-374

Type D-665 Designed as a trailing edge actuator for jet fighters. It has a normal peak load of 28,000 inch-pounds and a total angular travel of 30°. Speed is .675 R.P.M. with an average load of 14,000 inch-pounds on a 28 volt DC system (18.75 amps). Ultimate static load is 77,000 inch-pounds. Weight is 25½ lbs. Design incorporates auxiliary power take-off and non-jamming end stops.

TYPE D-665

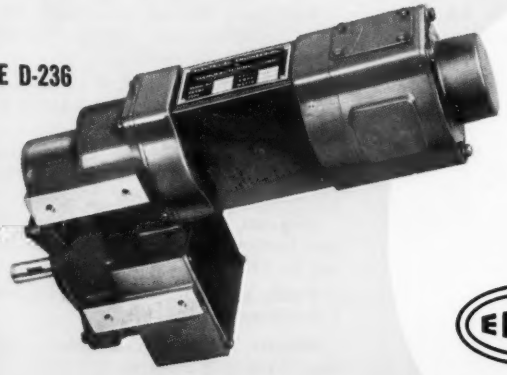
Type D-525 Double motor power unit for horizontal stabilizer of turboprop aircraft. Consists of small 1/15th h.p. continuous duty motor operating through a gear reduction for trimming in automatic flight, and a large intermittent duty 3½ h.p. motor with direct drive of 12,000 R.P.M. for manual operation. Dimensions of complete unit are 12½" x 7" x 3¾". Weight is 16½ lbs.

TYPE D-525



Type D-236 A rotary actuator for intermittent duty, delivering 200 inch-pounds at 107 R.P.M. on 24 volts DC. Unit includes magnetic clutch and brake, adjustable limit switch, cams, and thermal protector. Gear ratio is 28 to 1. Weight is 8½ lbs.

TYPE D-236



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Irbitis, Karlis, Prelim. Design Engineer, Canadair, Ltd.

Lueck, David W., M.S.E. (Aerodynamics), Staff Aerodynamicist, Hq. ARDC (Baltimore).

Metsger, Alfred B., S.M. in Ae.E., Capt. & Dir., Guided Missiles Div., BuAer, Dept. of the Navy.

Thrall, Edward W., Jr., B.S. in M.E. (Aero.), Design Specialist, Douglas Aircraft Co., Inc. (El Segundo).

Wead, Robert K., Chief Application Engineer, Marquardt Aircraft Co.

Elected to MEMBER Grade

Anderson, H. W., Mgr., Aviation Div., Whiting Corp.

Bennett, Theodore C., M.S.M.E., Tech. Supt., Engrg. & Devel. Services Dept., Naval Air Development Center.

Benscoter, Carl A., Vice-President—Operations, Mohawk Airlines, Inc.

Blanding, C. F., B.S.Ae.E., Mgr., Sales Engrg., AiResearch Mfg. Co.

Disher, John H., B.S. in M.E., Head, Free Flight Propulsion Section, NACA (Cleveland).

Haupt, Ulrich, Dipl. Ing., Chief Struct. Engr., Aero-Cal Engineers (Burbank).

Haven, Edward G., B.S.E.E., Mgr., Aviation Sales, General Electric Co. (Schenectady).

Hearn, Danny L., B.Sc.Ae.E., Chief Engr., Temco Aircraft Corp.

Hockett, Arthur M., B.S. in C.E., Sr. Ground Operations Engr., Boeing Airplane Co. (Wichita).

Joerger, Jerome C., M.S.E.E., Research Engineer "A," Aircraft Div., R & D Labs., Rheem Mfg. Co.

Kenworthy, Everett L., Degree of Metallurgical Engr., Proj. Engineer, Aviation Section, General Electric Co. (Los Angeles).

Kirk, John E., M.Ae.E., Group Leader, DIC Inst. Lab., M.I.T.

Kramer, Kenneth C., B. of M.E., Proj. Engineer-Pilot, Lear, Inc.

Kuklewicz, Edward F., B.Sc.M.E. (Aero.), Aerodynamics Engineer "A," Fairchild Aircraft Div., Fairchild Engine & Airplane Corp.

LaFrance J., Jr., B.S.M.E., Supvr. Struct. Test Section, The Glenn L. Martin Co.

Macartney, Allan U., Sr. Negotiations Engr., AGTD, Westinghouse Electric Corp.

Marshall, Beverly A., B.S.M.E., Designer "B," Boeing Airplane Co.

McKinnon, Roy A., M.S. in M.E., Aero. Research Scientist, LFPL, NACA.

McMahill, Victor W., Jr., B.S. in E.E., Asst. Mgr., Aviation Dept., Westinghouse Electric Corp. (Washington Office).

Morris, Joseph T., M.S.E.E., Vice-President, United Aircraft Products, Inc.

Moses, Harry C., B.S. in M.E., Supvr.-Engineer, Air Arm Div., Westinghouse Electric Corp.

Naegeli, Charles A., Jr., B.S.Ae.E., Proj. Engineer, Flight Refueling, Inc.

Nahigyan, K. K., M.E., Chief, Mech. Engrg. Div., Lewis Flight Propulsion Lab., NACA.

Nickey, William E., B.S.M.E., Cons.-Management Engineer, self-employed.

Perrill, Harlan K., M.Sc. in Engrg., Comdr., USN (Ret.); Sales Mgr., Schwien Engrg. Co.

Polleschultz, Charles J., Jr., Group Engr., McDonnell Aircraft Corp.

Reed, James F., B.S.Ae.E., Staff Member, Sandia Corp. (New Mexico).

Rodriguez, Edward, B.S. Engrg.-Physics, Aerodynamicist, North American Aviation, Inc. (Downey).

Russ, Kenneth M., Jr., B. of Ae.E., Sr. Aircraft Struct. Engineer, Lockheed Aircraft Corp. (Ga.).

Simpson, James E., B.S. in M.E., Assoc. Research Engineer "A," Boeing Airplane Co. (Seattle).

Stirgwolt, Ted F., M.S.E., Supvr., Engine Performance Analysis, General Electric Co. (Evendale).

Walch, Howard C., B.S.M.E., Engineer I, Sverdrup & Parcel, Inc.

Winkler, Eva M., Dr. rer. Nat., Physicist, Naval Ordnance Lab.

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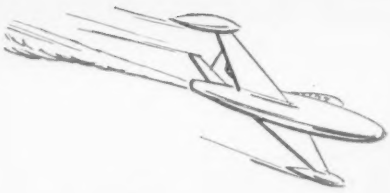
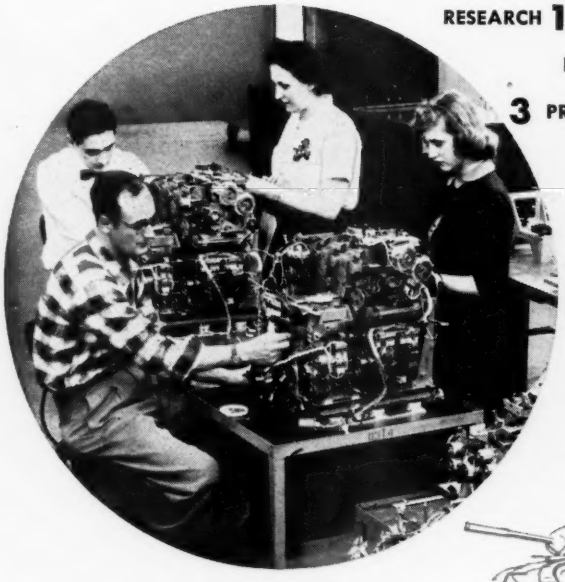


The 3 frontiers of know-how...

RESEARCH 1

DEVELOPMENT 2

3 PRODUCTION



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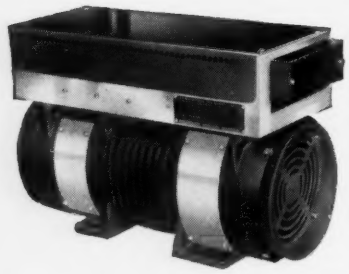

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Type Number	INPUT		OUTPUT			Approx. Weight Lbs.	Max. Alt. Feet	Designed to Government Part No.
	Volts	Amps	Volts	Phase	VA Rating			
12128	27.5	1	26	1	6	2.2	35000	AN3496-1
12126	27.5	2	26	3	10	2.3	35000	N1020-SK
MG-54	27.5	22	115/200	1	250	17	65000	E-5109
				3	250			
12142	27.5	22	115	1	250	13	35000	N-17158 Navy
				3	250			
12146-1	27.5	22	115	1	250	13	35000	53B6239 AF
12146-3	27.5	22	115	1	250	13	35000	—
				3	250			
MG-60	27.5	22	115	1	250	17	50000	53B6239 AF
MG-62	27.5	22	115	3	250	17	50000	AN3532-2
32E01	27.5	35	115	1	500	25	50000	AN3533-1
				3	500			
32E00	27.5	45-54	115	1	500	34	50000	AN3534-1
				3	750			
MG-57	27.5	100	115/200	1	1250	42	50000	E1737-1 Navy
				3	1500			
MG-61	27.5	100	115	1	1500	56	65000	53C6767
MG-64	27.5	100	115	3	1500	56	65000	—
MG-70	27.5	105	115/200	1	1500	56	65000	—
				3	1500			
1518 Mod. 1 & 2	27.5	130	115	1	1500	37.5	20000	—
				3	1800			
1518 Mod. 5	27.5	130	115	1	1500	37.5	35000	—
				3	1800			
32E06	27.5	180	115/200	1	2250	56	50000	E1725 Navy
				3	2500			
32E03	27.5	160	115	1	2500	61	50000	53B6227
32E09	27.5	180	115	1	2500	56	50000	—
				3	3000			

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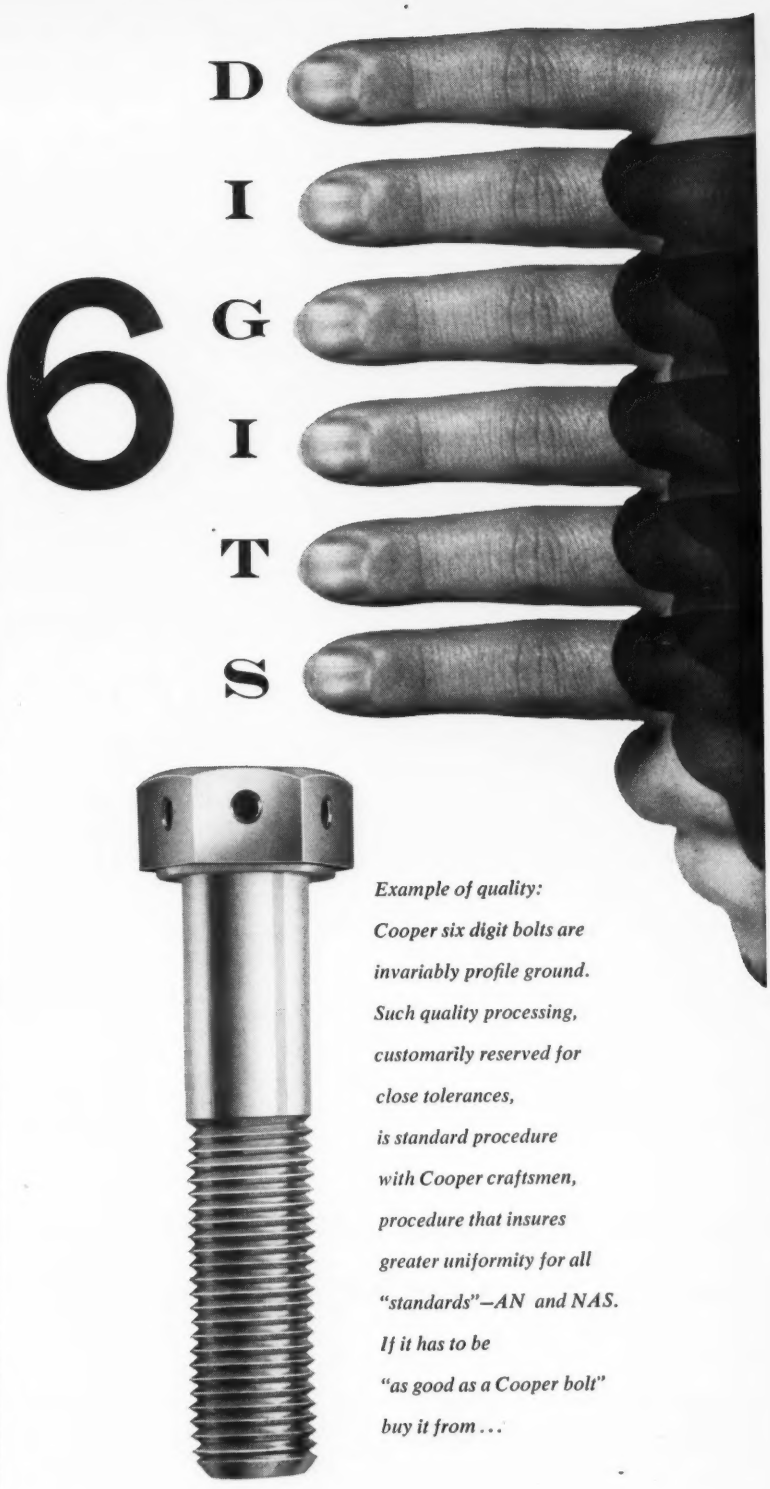

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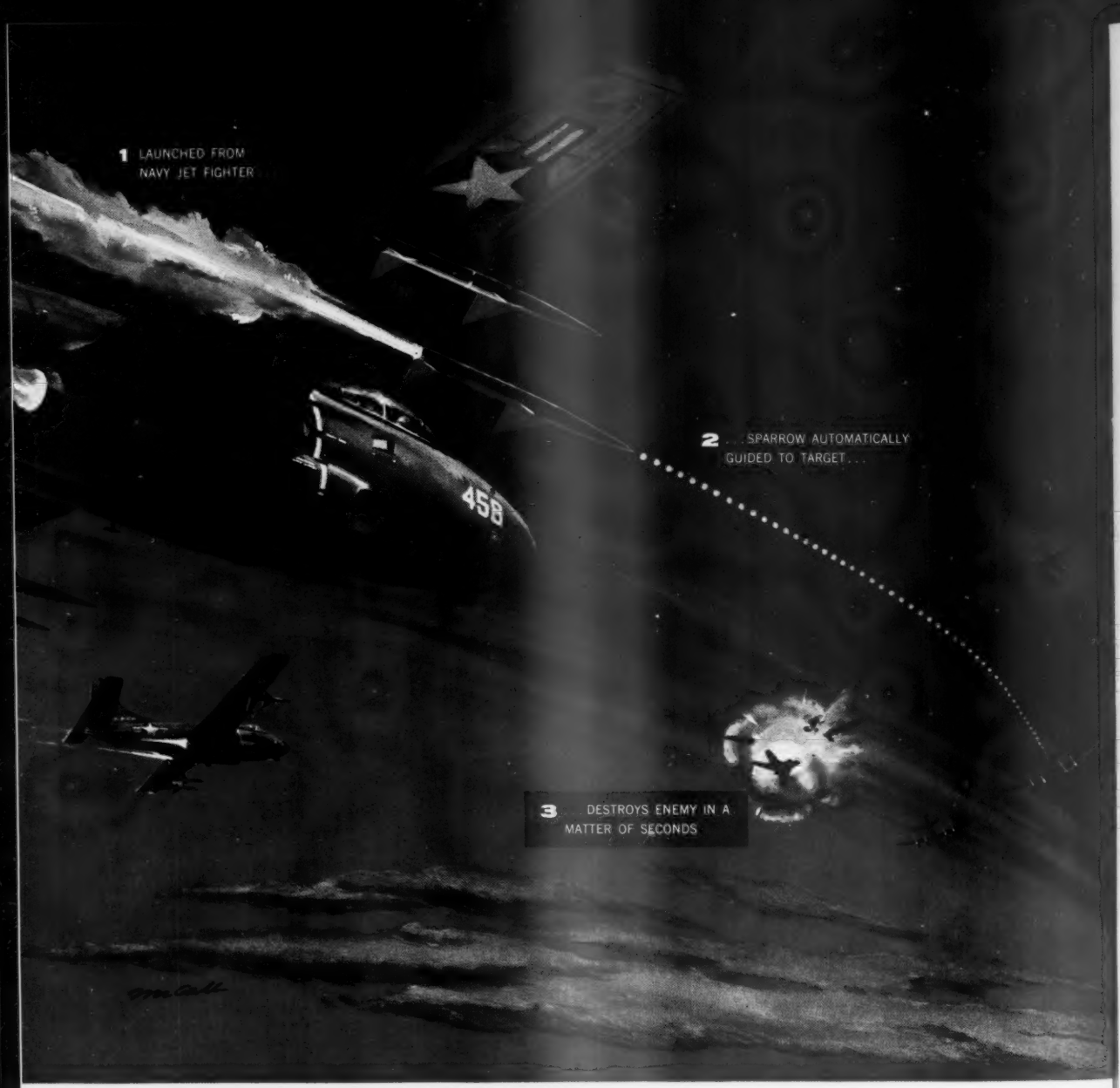

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Aerodynamics

Aerodynamic Loads on a Leading-Edge Flap and a Leading-Edge Slat on the NACA 64A010 Airfoil Section. John A. Kelly and George B. McCullough. *U.S., NACA TN 3220*, June, 1954. 33 pp.

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Boundary Layers in Three-Dimensional Flow. W. R. Sears. *Appl. Mech. Rev.*, July, 1954, p. 281. 39 refs. Review of the literature on investigations extending Prandtl's laminar boundary-layer theory to three-dimensional cases without axial symmetry covering such aspects as the independence principle, component separation, boundary regions, cylindrical and conical symmetry, and problems of turbulence.

Determining Skin Friction Temperature. William D. Murray and Lawrence Slote. *Aero Dig.*, June, 1954, p. 33. Graphical method to appraise basic problems.

Effect of Large Temperature Changes (Including Viscous Heating) upon Laminar Boundary Layers with Variable Free-Stream Velocity. Solomon Levy. *J. Aero. Sci.*, July, 1954, p. 459. 27 refs. Theoretical investigation to determine the conditions of skin friction and heat transfer of the flow.

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Investigation of Distributed Surface Roughness on a Body of Revolution at a Mach Number of 1.61. K. R. Czarnecki, Ross B. Robinson, and John H. Hilton, Jr. *U.S., NACA TN 3230*, June, 1954. 35 pp. 10 refs. Skin-friction drag tests on ogive-cylinders at zero angle of attack over a roughness range of 23–480 microinches root mean square and over a Reynolds Number range of 2.5×10^6–37×10^6.

Laminar Boundary Layer on Cone in Supersonic Flow at Large Angle of Attack. Franklin K. Moore. (*U.S., NACA TN 2844*, 1952). *U.S., NACA Rep. 1132*, 1953. 13 pp. 14 refs. Supt. of Doc., Wash. $0.20.

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Measurements of Turbulent Friction on a Smooth Flat Plate in Supersonic Flow. Donald Coles. *J. Aero. Sci.*, July, 1954, p. 433. 21 refs. Use of floating-element technique to measure directly the friction drag for Mach Numbers 2.0 to 4.5 and Reynolds Numbers from 3×10^5 to 9×10^6.

On the Approximate Solution of the Laminar Boundary-Layer Equations. Itiro Tani. *J. Aero. Sci.*, July, 1954, p. 487. Development of a simplified method extending the Polhausen approach to the basic problem.

On the Three-Dimensional Instability of Laminar Boundary Layers on Concave Walls. H. Görtler. (*Ges. d. Wiss. Göttingen, Nach. a. d. Math.*, No. 1, 1940.) *U.S., NACA TM 1375*, June, 1954. 32 pp. 10 refs.

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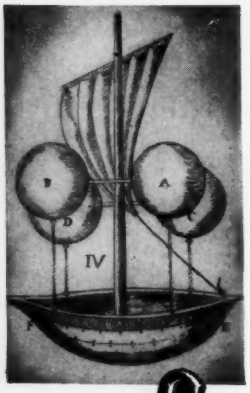

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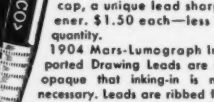

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Unsteady Compressible Flow in Ducts. W. Chester. *Quart. J. Mech. & Appl. Math.*, June, 1954, p. 247. Study of the establishment of steady subsonic-supersonic flow in a converging-diverging nozzle, with emphasis on the behavior of the initial period of unsteady flow.

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Analysis of Flight Measurements on the Airborne Path during Take-off. W. R. Buckingham and D. Lean. *Gt. Brit., ARC CP 156* (Oct., 1952), 1954. 27 pp. BIS, New York. $0.50.

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The Derivation of Airworthiness Performance Climb Standards. I—Qualitative Discussion. II—Mathematical Analysis. III—Numerical Application and Discussion. F. G. R. Cook and A. K. Weaver. *Gt. Brit., ARC R&M 2631* (July, 1948), 1954. 64 pp. BIS, New York. $4.15.

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Accidental Autorotation in Acrobatic Flight. Masao Yamana. *J. Japan Soc. Aero. Eng.*, May, 1954, p. 108. In Japanese. Analytical studies with refined procedures and design precautions to solve the problem.

An Analytical Investigation of Airplane Spin-Recovery Motion by Use of Rotary-Balance Aerodynamic Data. Stanley H. Scher. *U.S., NACA TN 3188*, June, 1954. 38 pp.

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A Second-Order Theory for Three-Dimensional Wings in Supersonic Flow. M. H. Clarkson. *Quart. J. Mech. & Appl. Math.*, June, 1954, p. 203. 10 refs. Development of a method utilizing Light-

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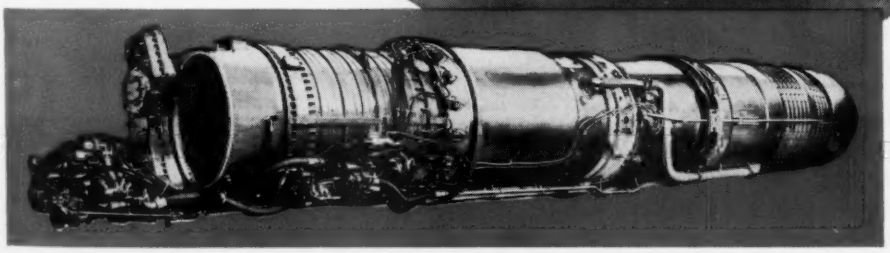

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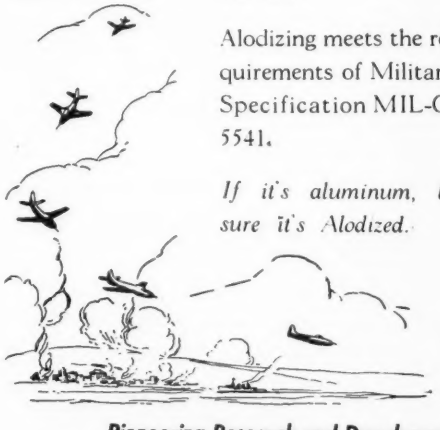

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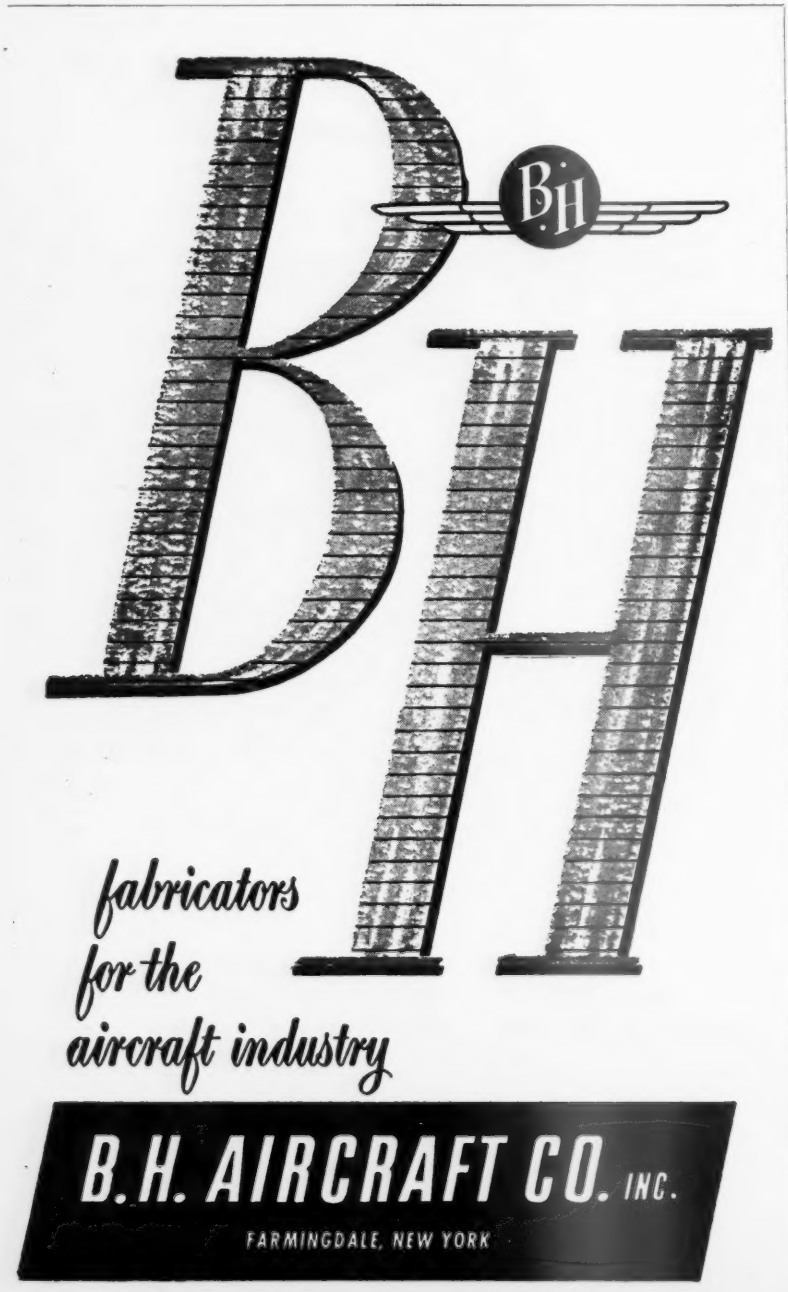

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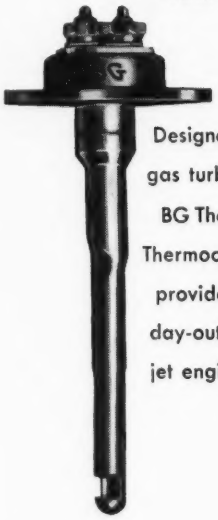

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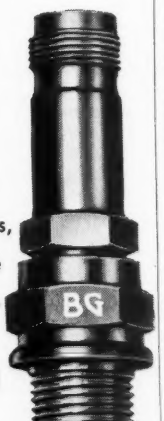

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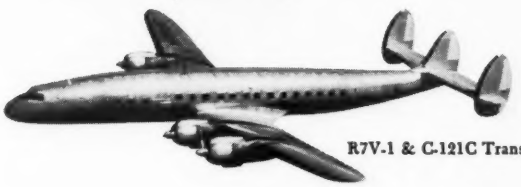

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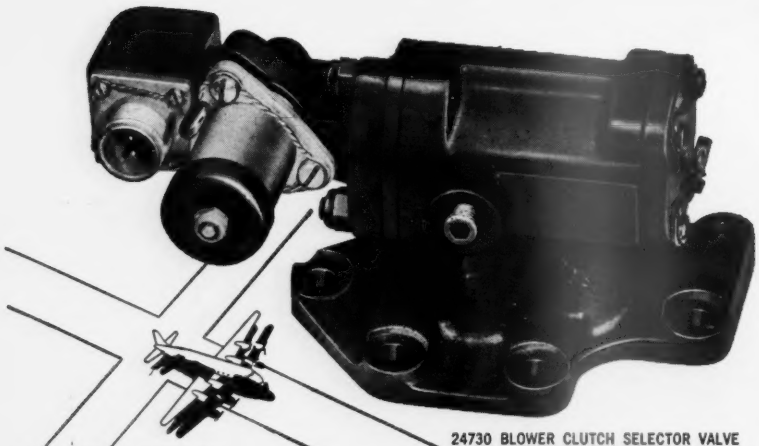

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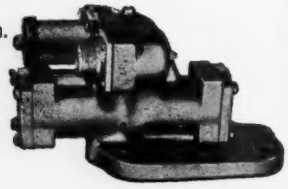

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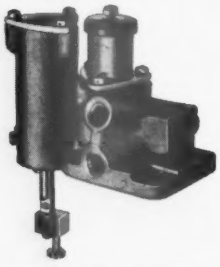

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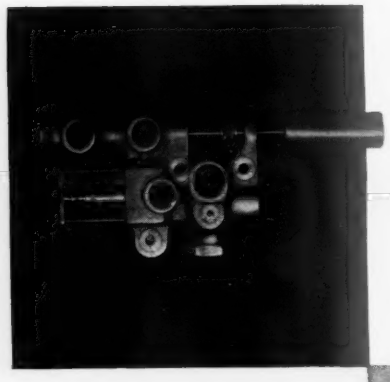

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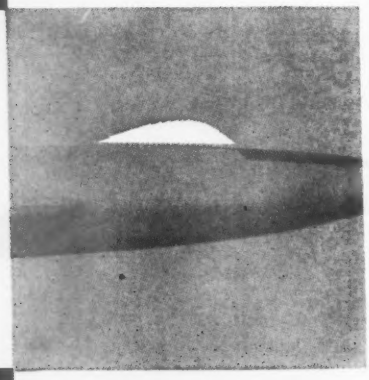

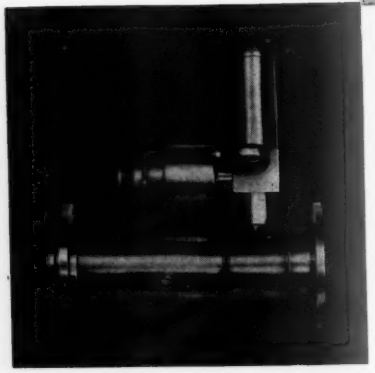

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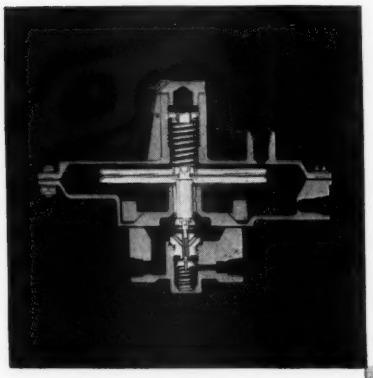

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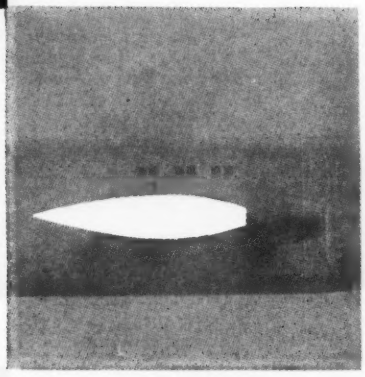

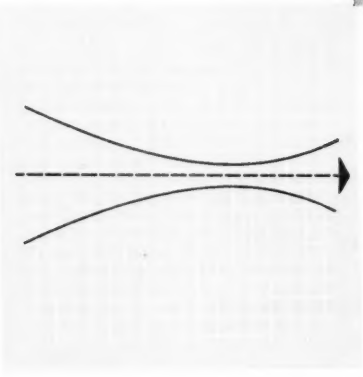

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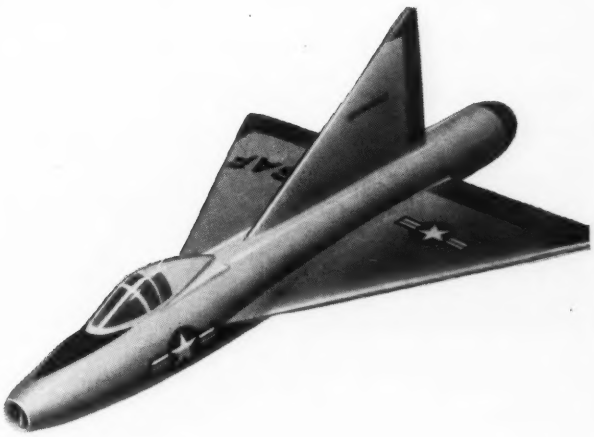

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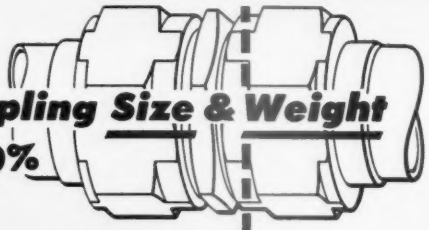

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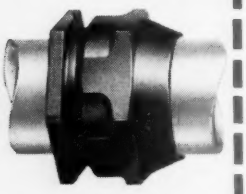

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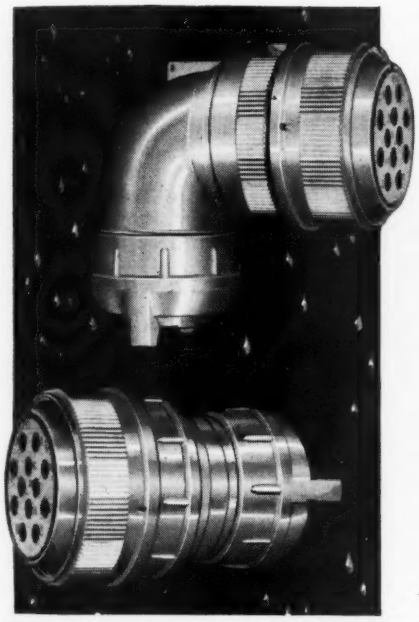

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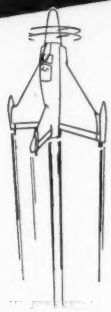

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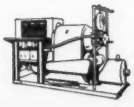

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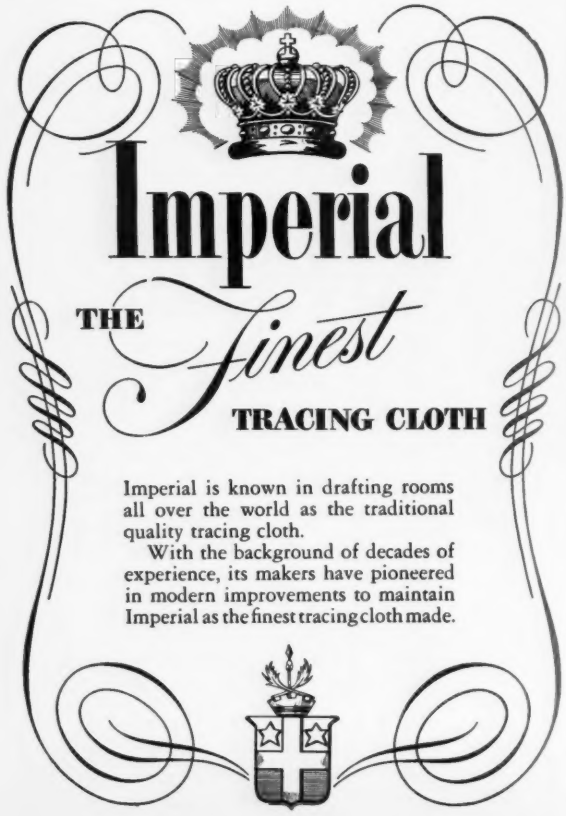
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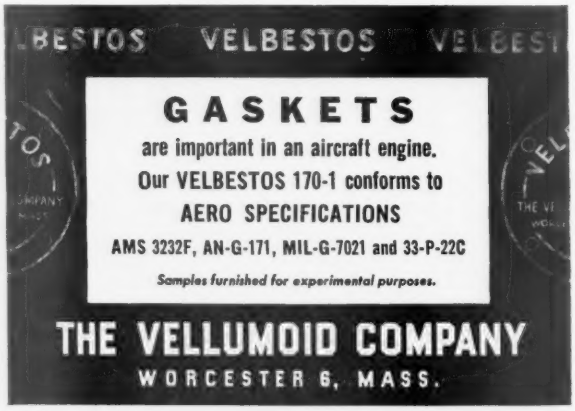

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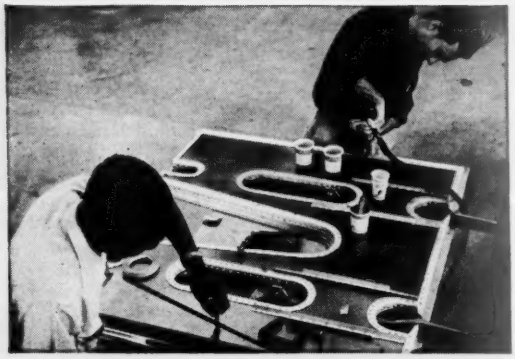

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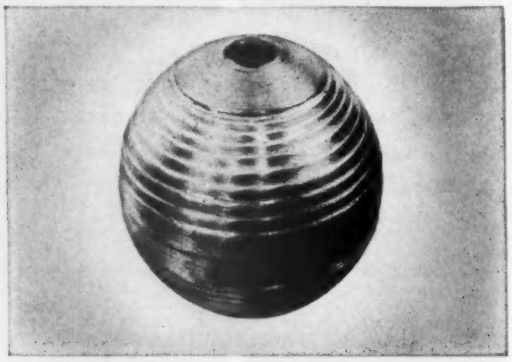

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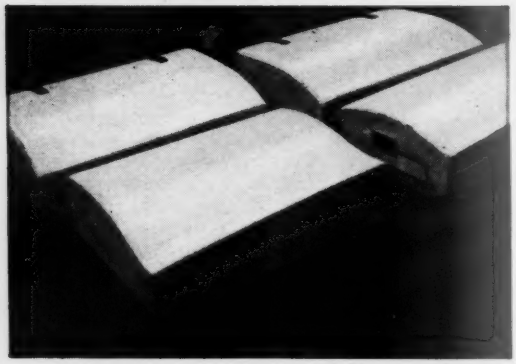

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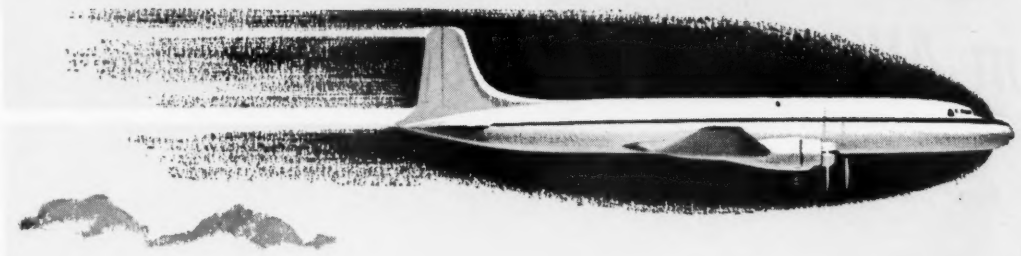

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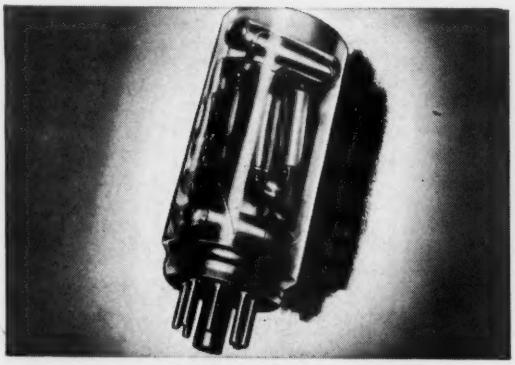

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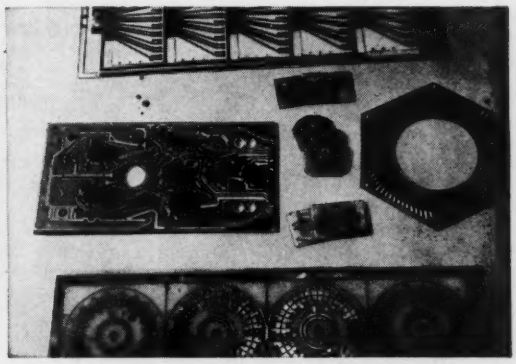

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Aeronautical Reviews — BOOKS

Aerodynamics

Selected Topics in the Light of Their Historical Development. By Theodore von Kármán. Ithaca, N.Y., Cornell University Press, 1954. 203 pp., illus., diagrs., figs. $4.75.

This delightful volume presents the history of aerodynamics through the eyes of one of its principal architects, Dr. Theodore von Kármán. The serious discussion is annotated with personal reminiscences. Thus we learn of the experiences of Prandtl's student, Karl Hiemenz, which enlisted Kármán's interest in vortex streets behind cylinders and of the alternate designation, avenue de Henri Bénard, for these vortices. We read of the invention of the term transonic, which according to the memory of the reviewer occurred just before a meeting of the NACA Aerodynamics Committee in 1944.

The book begins with a chapter on aerodynamic research before the era of flight, then a semiempirical science only loosely connected with the rational theory of the mechanics of fluids. An interesting figure compares the wing loading of birds with that of the Wright airplane and with Helmholtz's cube-square similarity law.

The next two chapters deal with the theory of lift and theories of drag and skin friction. Emphasis is on the development of fundamental ideas. The assessment of the relative contributions of Lanchester and Prandtl by an observer on the scene is of great historical value. I have already referred to the interesting story of the Kármán vortices. There is also one of Kármán's early analyses of pipe-flow data in terms of the Reynolds' Number.

A chapter entitled "Supersonic Aerodynamics" deals with compressible flow theory, shock waves, and transonic problems. Stability and aeroelasticity form the subject of another chapter. Here the spin of an airplane is compared to a love affair, and the prestige of the flutter department of an anonymous airplane company in California is established by a suitable anecdote.

The final chapter, "From the Propeller to the Space Rocket," is devoted to problems of propulsion. We learn that a race horse has the same specific power, horsepower per ton, as a good battleship. This chapter reviews the fundamental ideas of the new breed of jet power plants including the author's concept of the role of the large rocket.

Dr. von Kármán states in the preface that one of his aims in writing this book was "to remind persons engaged in the study or professional use of aerodynamic science how much mental effort was necessary to arrive at an understanding of the fundamental phenomena, which the present-day student obtains readily from books and lectures." This he has succeeded in doing in most interesting fashion.

DR. HUGH L. DRYDEN
Director, NACA
Washington, D.C.

Titanium

Increased Production, Reduced Costs, Through a Better Understanding of the Machining Process and Control of Materials, Tools and Machines, Vol. 3. By James Van Voast. (USAF Machinability Report.) Wood-Ridge, N.J., Curtiss-Wright Corporation, 1954. 153 pp., illus., diagrs., figs.

The significance of this series of volumes is well stated in the Preface, from which I take the liberty of quoting: "These machinability reports are an important part of industrial planning for defense mobilization. The present report differs from its predecessors in that a new engineering material is involved." The work consists of 13 chapters and an appendix. Chapter One condenses for review what is aptly termed the common sense of machinability. Chapter Two, devoted to getting acquainted with titanium, explains the various alloys and their properties, metallographic specimen preparation, and heat treatment methods; it includes an unusually fine series of metallographic enlargements. The deleterious influence of carbon content on machinability, as well as its connection with methods of refining, are duly noted.

The succeeding chapter deals with the principal machining difficulties typical of titanium. Abrasion, galling, and smearing on the cutting tool are analyzed for cause and remedy. The tendency of titanium to generate unusually high temperatures and pressures on the cutting tip is accounted for, and many of the revolutionary attempts to overcome this are dealt with in Chapter Four.

Drastic methods used to cool, to blanket chemically from oxidation, and to lubricate the cutting points led to no wholly satisfactory solution. Liquid CO_2, inert gases, and high-pressure jets below the tool—combined with low-pressure descending curtain jets—were all tried. The complete range of commercially available tool materials was spot tested. In many cases high-speed steels used under the proper conditions, "straight" carbides, and the jets mentioned appeared to ensure the practicability of satisfactory production machining. Ample graphic and tabular data describe the results of the tests.

Chapters 5 to 13, the body of the book, deal with the following operations, respectively: turning, milling, routing, drilling, tapping, abrasive cut-off, hack sawing, and belt and surface grinding. The job is well done—sound, well analyzed, and well presented.

Each of the chapters opens with a summary. To illustrate, I will quote the summary on milling: "Prevention of cutter chipping and breakage is the chief problem in milling. The short, individual chips characteristic of milling do not fall off but remain 'welded' to each tooth as it emerges from the cut. On the next revolution the chip has to be struck off. Often the bond is so strong that the tooth is chipped on impact. The best solution is to place the work in such a way that the cutter teeth finish their cuts in a direction parallel with the feed. Maximum 'bite' is thus taken at the

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start of the cut, and the 'welded-on' section is only a sliver. In slab milling this means a climb cut. In face milling it means lining up the edge of the work with the emerging side of the cutter periphery, a climb cut also. Rake is noted as the most critical tool angle."

In general, no simple solutions to the specific machining problems were found; rather, the best in past practice was extended. In tapping, an obviously critical operation, this called for larger tap drills, special points, interrupted flutes, large relief, few threads, chemically active cutting fluids, and low speeds. It might be noted here that recent studies confirm the ability of 50 per cent depth threaded holes to break the studs.

A brief appendix contains recent information on machining high-temperature alloys.

In view of the present aircraft and other military uses of titanium and of its commercial future, the report should be most welcome to industry.

Having reviewed the first two volumes, I am in a position to express my feeling that there has been a steady improvement. Unity and usability have greatly enhanced the value of the document. The trend of communication emphasis toward those directly concerned with the men and machines of production makes it a reference that should be at hand in any plant beginning its experience with titanium. It is readable and yet chock-full of information.

JAMES L. G. FITZPATRICK

Instrument Engineering. Vol. 2, Methods for Associating Mathematical Solutions with Common Forms.

By Charles Stark Draper, Walter McKay, and Sidney Lees. New York, McGraw-Hill Book Company, Inc., 1953. 827 pp., diagrs., figs. $15.

Instrument Engineering, Volume 2, is a valuable reference for methods of solution of equations describing the dynamics of a control system. Many physical processes can be accurately described by lumped parameters, and thus the dynamic behavior of the system can be expressed in terms of linear integro-differential equations. Volume 2 provides an effective means of solution of these integro-differential equations and presents examples of the equations commonly found in all types of control systems. Many of the illustrated solutions, with slight modifications, will provide the engineer with a solution to his problem, while the methods of solution are clearly explained and provide the reader with a systematic approach to the solution of more complex problems.

There are different types of controllers: pneumatic, hydraulic, mechanical, or electrical; often, complex control systems employ combinations of these. Whatever the medium of control, similar systems will have inte-

gro-differential equations of the same form with similar dynamic solutions. The nondimensional approach to the dynamic problem is well illustrated, and its use provides solutions that may be applied to any type or combinations of control medium. The use of nondimensional plots throughout the book is a valuable aid to the control designer.

The solution of the generalized differential equations by classical, operational, and weighting function methods is presented in the first few chapters. This will provide the reader with sufficient background to follow the remaining discussions.

The solutions of first- and second-order differential equations with constant coefficients is considered in detail. These solutions afford useful illustrations of general procedures and provide a basis for a system of definitions which is generally effective for discussions of all differential equations. Since many physical systems can be approximated as second-order systems, the results obtained for different driving functions and initial conditions are of particular interest.

The transient stability of mathematical solutions is discussed in detail. The concepts of stability defined for operating components in a control may be applied to solutions of integro-differential equations. A graphic and analytic approach is used to describe the stability of solutions for linear integro-differential equations associated with conservative and nonconservative systems.

Methods of solving third- and fourth-order characteristic equations are also included in the text.

Graphic methods for obtaining the response of a control system to sinusoidal driving functions are discussed. These systematic methods are a great labor-saving device in analysis and synthesis of control systems.

The latter part of the text discusses the relating function forms from pulse function responses. The Fourier transform approximation formulas, for a stepped-curve and also a trapezoidal approximation, are used. Errors and limitations of this method are considered.

The fundamentals and applications of numerical analysis by the number series transformation method is included in the last chapter.

It is felt that *Instrument Engineering, Volume 2,* will be a valuable asset to engineers who are engaged in the analysis and development of control systems.

BERNARD J. O'CONNOR
Senior Engineering, Control Section
Eclipse-Pioneer Division
Bendix Aviation Corporation

Book Notes

AERODYNAMICS

Flow and Fan; Principles of Moving Air Through Ducts. C. Harold Berry. New York, The Industrial Press, 1954. 226 pp., diagrs., figs. $4.00.

The title of the book is derived from the two major divisions of treatment: (1) the flow of gas through duct systems, and (2) fan performance and control. In the seven chapters on gas flow, basic data and methods for finding system resistance are presented, and the final six chapters are devoted to the practical task of selecting a fan for a given duty. *Flow and Fan* was written to meet the needs of students interested in acquiring a working knowledge of ventilation and will be useful to practicing engineers as well. It is an outgrowth of a compilation of lecture notes developed for a course at Harvard University, where the author is Gordon McKay Professor of Mechanical Engineering. While certain portions are at an elementary level for those who want an introduction to the subject, other portions, including a new treatment of some topics such as equivalent orifice and the space-saving Gibson tapered enlargement, will be worthy of the attention of the most advanced. Subjects covered include factors in gas-flow measurement, head, density, pressure, boiler draft, losses in laminar and turbulent flow through various shapes of duct, fan types and performance, and fan selection and model testing.

Air-Plane Flight. A. York Bramble. London, Sir Isaac Pitman & Sons, Ltd., 1952. 366 pp., illus., diagrs., figs. 35*s*.

An introduction to the study of flying in the "heavier-than-air" type of machine. The subject is treated in a novel way and is written in a style that makes the book equally suitable as a "reader" dealing with preliminary flights, as a school book where aviation is introduced into the science syllabus, for aviation cadets and pilots in training, and for general readers interested in the subject. Test questions and a technical vocabulary are useful features of the book.

FUELS & LUBRICANTS

Lubrication of Industrial and Marine Machinery. William Gordon Forbes. Revised by C. L. Pope and W. T. Everitt. 2nd Ed. New York, John Wiley & Sons, Inc., 1954. 351 pp., illus., diagrs., figs. $6.50.

The purpose of this book is to provide a manual that may be used to explain the fundamental characteristics of conventional lubricants. Some of the more common basic mechanisms, such as bearings, gears, pumps, and compressors, have been explained in some detail. The integration of the lubrication principles with the lubrication requirements of mechanisms, as explained in this book, will enable one to solve lubrication problems. An effort has been made to provide a logical sequence of study. The first 14 chapters deal with the chemistry, refining, compounding, and specifications for lubricants. The second part, chapters 15 through 32, explain the lubrication requirements of the most common types of machinery. The concluding chapters give practical examples of how the knowledge gained may be applied to the lubrication of equipment.

GLIDING

On Being a Bird. Philip Wills. London, Max Parrish and Company Ltd., 1953. 231 pp., illus., diagrs., figs. 15*s*. 16*d*. ($3.00).

A narrative based on the experience and accumulated knowledge of a sailplane pilot. He tells how sporting gliders were used in the early days of the development of radar and the story of many of his flights, from an early cross-country flight in 1934 to the day he became World Champion in 1952.

INSTRUMENTS

Kollsman Precision Aircraft Instruments. Elmhurst, New York, Kollsman Instrument Corporation, Subsidiary of Standard Coil Products Co., Inc., 1954. 283 pp., illus., diagrs., figs.

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METALS & ALLOYS

Procedures in Experimental Metallurgy. A. U. Seybolt and J. E. Burke. New York, John Wiley & Sons, Inc., 1953. 340 pp., illus., diagrs., figs. $7.00.

The primary aim is to describe most of the important laboratory techniques now used to prepare metals and alloy specimens for further study. The preparation of metal samples up to the point of making observations on the properties of the metal is the theme of guiding principle or the book. Investigational techniques such as microscopic examination, X-ray diffraction methods, thermal analysis, and technical testing are omitted because of their satisfactory treatment in other literature. The authors, both of whom are associated with the General Electric Company, slanted their work toward investigators new to the study of metals but have also kept in mind the needs of the younger research metallurgist and those directing programs of metals research.

Contents: Methods of Obtaining High Temperatures. Measurement of High Temperatures. Control of Temperature. Refractories. Controlled Atmospheres. Vacuum Systems. Melting and Casting. Heat-Treating Techniques. Fabrication of Metals. Powder Metallurgy. Preparation of Pure Metals. Preparation of Metal Single Crystals.

NATURAL FLIGHT

The Intrinsic Range and Speed of Flight of Insects. Brian Hocking. (Royal Entomological Society, London, Transactions, Vol. 104, Part 8, October 23, 1953.) London, The Society, 1953. 129 pp., illus., diagrs., figs. £2. 8*s*.

In Part I, Professor Hocking discusses in general the flight of animals and the particular features of insect flight. Most of the field work for this monograph was done in the northern Manitoba region of Canada. The energy resources of some of these northern species have been investigated (Part II) and balanced against their power requirements in flight (Part III). After consideration of the efficiency of utilization (Part IV), reasoned estimates of the distance that they might travel in still air are arrived at (Part V). Additional observations on the weight of the flight muscles permit estimates also of the maximum air speeds of which these insects are capable (Part VI). Similar observations have been made on the honey bee and on flies. A general discussion and a summary of conclusions are given in Part VII. The book concludes with four appendixes of tables and symbols and a bibliography of about 500 references.

POWER PLANTS

Turbine and Jet-Propelled Aircraft Powerplants. James P. Eames. New York, Chartwell House, Inc., 1954. 237 pp., illus., diagrs., figs. $5.25.

This book is based on the author's 24 years of experience as an aeronautical engineer, primarily in the field of military power plants. He is a Major, USAF, and a consulting aeronautical and mechanical engineer. Designed as a familiarization text on the subject, the book bridges the gap between the conventional reciprocating engine and the gas turbine. Technical design and mathematical phases are presented simultaneously with the types of power plants to which they apply. Major foreign trends are covered at length. In addition to an introductory chapter on principles and chapters on the various classes of jet power plants, one chapter each is devoted to maintenance considerations and construction materials. The appendix, which comprises almost one half of the book, contains data on the development and design of the world's current turbopower plants and military and civil jet aircraft. The author has provided many illustrations as well as a glossary of terms and a subject index.

STRUCTURES

Stress Concentration Design Factors; Charts and Relations Useful in Making Strength Calculations for Machine Parts and Structural Elements. R. E. Peterson. New York, John Wiley & Sons, Inc., 1953. 155 pp., illus., diagrs., figs. $8.50.

The purpose of this book is to place in the designer's hands information that will enable him to improve his design calculations to the end that failure will be less prevalent and better balanced designs will be achieved. The book is to be regarded primarily as a working tool. It is not intended to be a textbook in the usual sense, and therefore only enough background and references are given to enable the reader to explore the subject further if he so desires. In order to increase its utility as a reference book, a spring binding, thumb-indexing, and full-page charts have been incorporated. Some parts of the book have been used in a Westinghouse–University of Pittsburgh Graduate Study Program. A valuable feature of the book is the collection of 174 literature references. The author, who is Manager of Mechanics Department, Westinghouse Research Laboratories, has drawn heavily from the work of Timoshenko, Goodier, Hetényi, Frocht, and Neuber.

Contents: List of Symbols. 1, Definitions and Design Relations. 2, Grooves and Notches. 3, Shoulder Fillets. 4, Hole in a Plate or Shaft. 5, Miscellaneous Design Elements (such as Gear Tooth, Press-Fitted or Shrink-Fitted Members, Bolt Head, Turbine-Blade or Compressor-Blade Fastening (T-Head), Helical Spring, Member of U-Shape, Angle and Box Sections, Rotating Disk with Hole). Appendix A, Stress Relations for Member with Single Groove or Notch. Appendix, B, Application of Mohr Theory for Fatigue of Brittle Materials. Appendix C, Derivation of Relation for Limited Number of Cycles. Appendix D, Derivation of Combined Stress Relations. References.

THERMODYNAMICS

Selected Combustion Problems; Fundamentals and Aeronautical Applications. Combustion Colloquium, Cambridge University, England, December 7 to 11, 1953. Advisory Group for Aeronautical Research and Development (AGARD), NATO, Palais de Chaillot, Paris. W. R. Hawthorne, J. Fabri, Editors; D. B. Spalding, Assistant Editor. London, Butterworth's Scientific Publications; Distributed in the United States by NACA, Washington, D.C., 1954. 534 pp., illus., diagrs., figs.

In addition to the papers presented at the Colloquium which are listed below, this volume contains the edited discussions of the papers and the authors' replies.

Contents: Preface, Theodore von Kármán, Introduction, J. Surugue.

Laminar Flame Propagation: Fundamental Approach to Laminar Flame Propagation, Theodore von Kármán and S. S. Penner. Étude Aérothermodynamique de la Combustion, Jean Fabri. Diffusion Processes as Rate-Controlling Steps in Laminar Flame Propagation, Dorothy M. Simon. Some Experimental Results Relating to Laminar Flame Propagation, J. W. Linnett. Ignition and Combustion in a Laminar Mixing Zone, Frank E. Marble and Thomas C. Adamson, Jr. Use of Spectroscopy in Elucidating Reaction Mechanism, A. G. Gaydon. Spectroscopic Studies of Premixed Laminar Flames, S. S. Penner.

Turbulent Combustion: Quelques Résultats et Méthodes Classiques d'Étude des Écoulements Turbulents, Jean-J. Bernard. Experimental Studies on Turbulent Flames, Arch C. Scurlock and John H. Grover. A Turbulent Flame Theory Derived from Experiments, Béla Karlovitz.

Solid and Liquid Propellants: The Combustion of Double-Base Propellants, Gordon K. Adams and Leonard A. Wiseman. The Mechanism of Combustion of Solid Propellants, Richard D. Geckler. Combustion of a Single Droplet and of a Fuel Spray, D. B. Spalding. Combustion Instability in Liquid-Propellant Rocket Motors—A Survey, Chandler C. Ross and Paul P. Datner.

Technical Combustion Problems: The Problem of Combustion at High Altitude, Peter Lloyd and Brian P. Mullins. Stabilisation des Flammes par des Obstacles, M. Barrére et A. Mestre. Combustion in Vitiated Air, Brian P. Mullins. Quelques Propriétés de la Combustion Pulsatoire: Le Pulso-Reacteur, Action des Carburants Dopés, J. Bertin.

Members Elected (*Continued from page 111*)

Roberts, Edward H., B.S. in Ae.E., Stress Analyst—Jr. Engineer "A," Boeing Airplane Co. (Wichita).

Rosenman, Uri, B. of Ae.E.

Scoledes, A. G. M., M.Sc., Research Engineer, Inst. for Air Weapons Research, Univ. of Chicago.

Sirotnak, John F., Stress Analyst, Republic Aviation Corp.

Silverman, Ralph E., Engineer-Aero. Dept., Grumman Aircraft Engrg. Corp.

Sulich, Janusz S. H., M.S. in Ae.E., Engineer-Power Steering Devel. Engrg. Div., Chrysler Corp.

Tucker, Henry A., Jr., B.S.Ae.E., Jr. Engineer-Struct., North American Aviation, Inc. (Columbus).

Ullock, Malcolm H. W., B.S.A.E., Jr. Engineer-Aerodynamics, Chance Vought Aircraft, Inc.

Webb, Jack, B.S. in Ae.E., Aerodynamics Engineer, Douglas Aircraft Co., Inc. (Tulsa).

Webb, Robert L., B.S. in Ae.E., Liaison Engineer, Douglas Aircraft Co., Inc. (Tulsa).

Welliver, Lyman H., A. in Ae.E., Jr. Engineer "A," Field Service Analysis Group, Boeing Airplane Co. (Wichita).

Wilcox, Donald E., B.S.E. (Aero.), Jr. Research Engineer, Republic Aviation Corp.

Wolfe, Robert R., B.S. in Ae.E., Aerodynamics Group, Chance Vought Air craft, Inc. (Dallas).

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Aircraft Performance Engineer—GS-11, $5,940 per annum; GS-9, $5,060 per annum. Calculation and compilation of engineering data for use in aircraft characteristic summary sheets; responsibility for obtaining and evaluating latest configuration data on new aircraft; perform mathematical calculations on special aerodynamic problems. Applications may be submitted on Standard Form 57, Application for Federal Employment to Department of the Navy, Bureau of Aeronautics, Personnel Division, Attention: PE-212, Washington 25, D.C. Standard Form 57 is available at U.S. Post Offices, or may be obtained by writing to the Personnel Division, Bureau of Aeronautics. Visitors to the Washington area may call at Room 3909 of the Main Navy Building, 19th and Constitution Ave., N.W., Washington, D.C.

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619. Senior Engineer—Instrument Design—To fill a highly responsible position with a small, well-founded Southeastern instrument manufacturer specializing in air-borne electromechanical, electronic, and photographic equipment. Applicant should have approximately 10 years' experience, plus a proved creative ability. Will have the responsibility for designing new products to be added to our present line, and must be capable of carrying a product development program through all stages from conception to production. This is an excellent opportunity for a properly qualified engineer who is seeking the advantages of being associated with a young, progressive company. Salary is open and depends on experience and ability. Send résumé of academic and professional background and recent photograph.

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610. Engineers (Career Opportunity)—Important aircraft engine accessory manufacturing company in Central Connecticut has openings for graduate engineers in the Project Engineering Department. These positions are open for men with: (1) A background of servo theory for dynamic analysis of feedback control systems, as applied to turbojet and turboprop engines. Will be required to set up and perform system analysis by use of analog computer equipment. (2) A background in fluid mechanics to work on hydraulic control development and fuel systems for turbojet engines. Will be required to execute design and performance analysis for steady-state and transient conditions. Also have several interesting openings for recent Mechanical and Electrical Engineering graduates. Ideal suburban location for working and living. Send résumé of education, experience, and salary requirements.

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Available

617. Aircraft Electronics Specialist—B.S. in Electrical Engineering with graduate work toward Master's Degree. Four years of professional experience in aircraft installation analysis, complex system development, servomechanisms, field engineering, radar, computers, periodic maintenance studies, and instruction of technician classes. Experienced supervisor of engineers and technicians. Broad practical experience as radio technician for seven years. Wide experience in work directly connected with all types of military and commercial aircraft. Primary interest: aircraft electronics development programs from viewpoint of aircraft maker to reduce growing electronic monster trend. Desires position with company offering job rotation to broaden engineers for management training. Age 29.

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615. Administration and/or Sales—B.S. in Mechanical Engineering. Age 37. Seventeen years' experience, of which 14 were in aircraft industry. Broad general engineering and technical representation experience, as well as research and development at both private and government policy-level. Considerable experience in aerodynamics. Pilot, former officer U.S. Marine Corps Aviation. Foreign experience, trilingual. Present income $14,000. Available about October 1.

614. Graduate Aeronautical Engineer—More than 14 years' experience. Has been granted several patents. Seeks opportunity to use inventive ability.

613. Aeronautical Engineer—B.S. (Math.), M.S. (Aero. Engrg.). Age 32; 3½ years' industrial experience in project design, flight testing, aerodynamics. One year research work. At present engaged in design and construction of wind tunnel. Four years' military flying experience. Desires position teaching Aeronautical Engineering or related subjects. Available September.

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612. Professor—Ph.D. in Physics, 1939. Thirteen years in Government aeronautical research. Approximately 24 papers covering wing, fuselage, propeller, and jet aerodynamics relating to stability and control; supersonic wing theory; boundary layer; turbulence; jet noise. Has had supervisory responsibility for theoretical and/or experimental research in stability and control, supersonic wing theory, boundary layer, turbulence, aerodynamic heating, shock-wave phenomena. Experienced lecturer and consultant. Interested in post as professor or department head; salary secondary.

611. Administrative—B.S.E.E. Age 39. Fourteen years' aviation experience including design, production control, stores, aircraft modifications, air-line project and maintenance engineering, new aircraft and equipment specifications and administration, contract administration. Specialization on air conditioning and cargo and passenger accommodation design requirements. Experience as a chief engineer. East Coast location preferred. Salary open.

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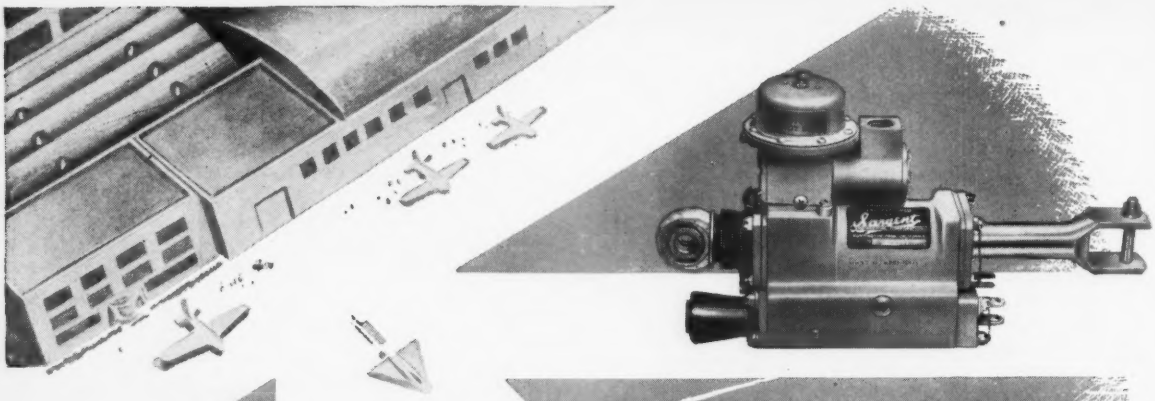

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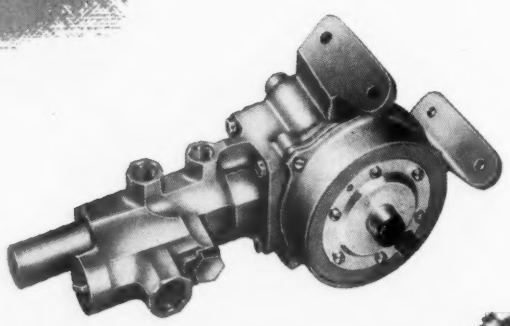

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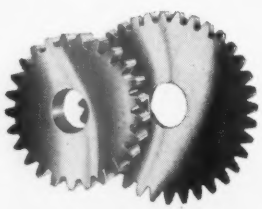

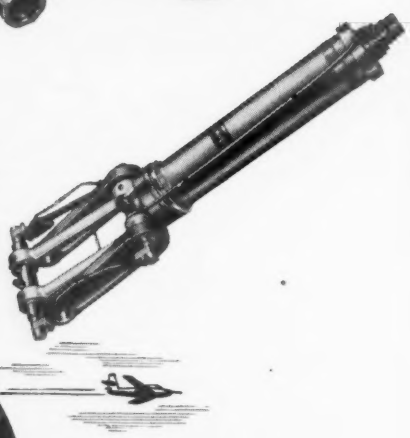

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ASC-1 Thermostat Metal Strip. Descriptive 6-page bulletin. **American Silver Co., Inc., 36-07 Prince St., Flushing 54, N.Y.**

Ceramic Coatings for High Temperatures. Technical 8-page brochure entitled, "Answers to Red Hot Problems." **California Metal Enameling Co., 6904 E. Slauson Ave., Los Angeles 22, Calif.**

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Conventional & Self-Locking Type Set Screws. Descriptive 24-page catalog No. 19. **Set Screw & Mfg. Co., 310 Main St., Bartlett, Ill.**

Series 32FE Engine Nuts. Designed for engine use where temperatures do not exceed 550°F. **Standard Pressed Steel Co., Jenkintown, Pa.**

O-Rings, Back-Up Rings, & Hydraulic Packings. 24-page descriptive facilities and products catalog. **Stillman Rubber Co., Dept. C, 5811 Marilyn Ave., Culver City, Calif.**

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